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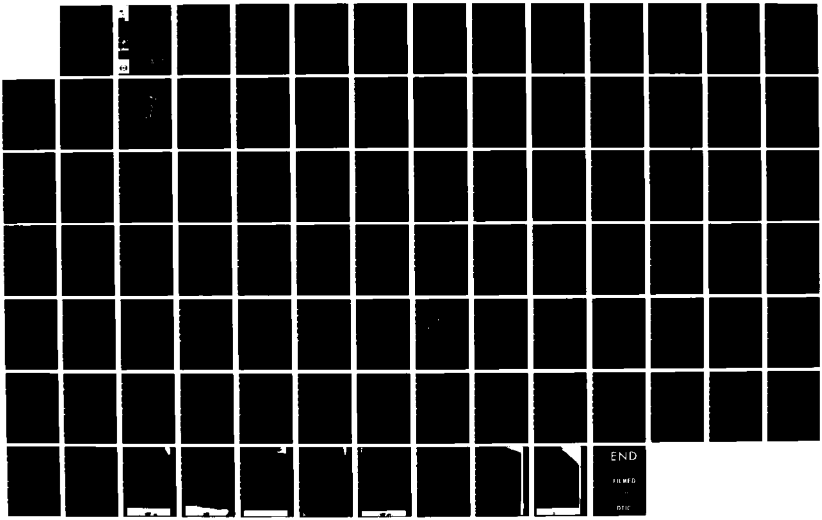

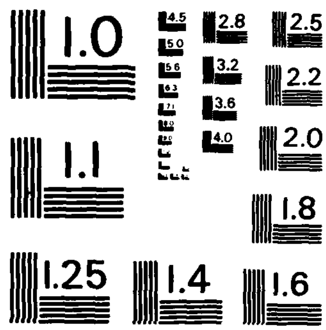

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WATER SUPPLY ANALYSIS STUDY FOR THE ISLAND OF SAIPAN

by

Janet S. Condra

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
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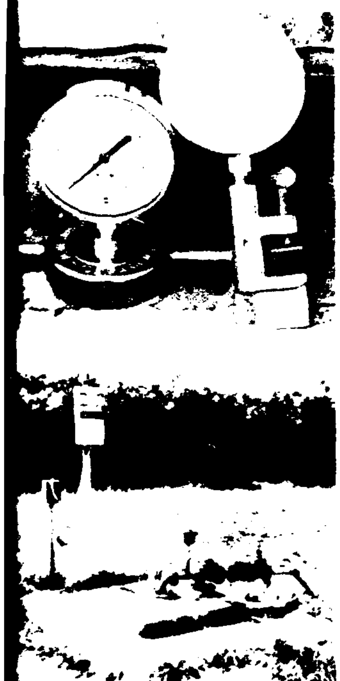

US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

September 1985

Final Report

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ENVIRONMENTAL LABORATORY

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Saipan
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents the results of a water supply analysis study for the Island of Saipan, located in the Commonwealth of the Northern Marianas. The Saipan water system is characterized by leaks, poor quality water, inadequate quantity of water, and deteriorated transmission lines. Several water supply alternatives for public water use on Saipan were evaluated. These alternatives involve developing new sources and/or improving the distribution network.

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20. ABSTRACT (Continued).

Part II of this report describes the water resources on Saipan, potential sources for future development, and analyses of six alternatives related to sources. These source-related alternatives represented various combinations of using existing sources, adding new sources, abandoning poor quality wells, and leak repair.

Alternatives involving the distribution system improvements are described. These alternatives included the improvements suggested by a 1982 contractor report and various modifications to the existing system including service lateral repair, improvement of system operations, and installation of a dual system. Complete replacement of the distribution network was also evaluated.

A computer model of the distribution network was developed and then calibrated using fire flow test results. This model was used in evaluating the distribution alternatives. The model will be useful in future management of the system.

Three combinations of source and distribution alternatives offer advantages of source adequacy, water quality improvement, and operational simplicity. Order of magnitude costs for each alternative are given.

PREFACE

This report presents the results of the water supply task of the Comprehensive Study of the Water and Related Land Resources of the Commonwealth of the Northern Mariana Islands. This work was conducted by the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., for the US Army Engineer Division, Pacific Ocean (POD).

This report was prepared by Ms. Janet S. Condra, Water Resources Engineering Group (WREG), Environmental Engineering Division (EED), Environmental Laboratory (EL), WES. Dr. Thomas M. Walski of WREG provided technical guidance for the study. Ms. Cheryl M. Lloyd and Ms. Kathy M. Smart, both of WREG, provided technical assistance. Technical review was provided by Dr. Walski and Dr. Joe M. Morgan, Auburn University.

The study was conducted under the direct supervision of Dr. Michael R. Palermo, Chief, WREG, and under the general supervision of Mr. Andrew J. Green, Chief, EED; Dr. Raymond L. Montgomery, Acting Chief, EED; and Dr. John Harrison, Chief, EL.

The study managers at the POD were Mr. Gene P. Dashiell and Mr. Samson Mar, both of the Project Formulation Section, Planning Branch. Mr. Hudson Kekaula assisted Ms. Condra in the field and provided valuable background information for the study. Division and District Engineers during the study were BG Robert M. Bunker and COL Michael M. Jenks, respectively.

COL Robert C. Lee, CE, was Commander and Director of WES during the conduct of the study. COL Allen F. Grum, USA, was Director of WES during the preparation and publication of this report. Mr. Fred R. Brown and Dr. Robert W. Whalin were Technical Directors.

This report should be cited as follows:

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CONTENTS

* Appendix B is an oversize map and is enclosed in the pocket in the back cover of this report.

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
feet	0.3048	metres
gallons (US liquid)	3.785412	cubic decimetres
horsepower (550 foot-pounds per second)	745.6999	watts
inches	25.4	millimetres
miles (US statute)	1.609347	kilometres
pounds (force) per square inch	6894.757	pascals

WATER SUPPLY ANALYSIS STUDY FOR THE ISLAND OF SAIPAN

PART I: INTRODUCTION

Background

1. As the largest island in the Commonwealth of the Northern Mariana Islands (CNMI), Saipan serves as the governmental, transportation, communication, commercial, and educational center for the CNMI. The need for an improved water system is eminent because of the importance of Saipan in the CNMI and the significance of tourism as a major industry on the island.

Purpose and Scope

2. The US Army Engineer Division, Pacific Ocean (POD), is conducting the Comprehensive Study of the Water and Related Land Resources of the Commonwealth of the Northern Mariana Islands. The US Army Engineer Waterways Experiment Station (WES) was requested to provide technical assistance to the POD in carrying out the water supply portion of this study. This report contains the results of analyses by WES.

3. The purpose of this report is to document the results of a water supply analysis study for the Island of Saipan. Part II of this report contains a description of the water sources on Saipan, a discussion of the water use, and analyses of source-related alternatives for improving the water supply and distribution system. Part III contains a discussion of alternatives for improving the distribution network. Conclusions drawn from the analyses in Parts II and III are given in Part IV.

4. The WES effort involved developing an understanding of the existing Saipan water system, developing and calibrating a computer model of the distribution system, and analyzing alternative modifications of the system using the model. The computer model was developed using the water distribution analysis and pipeline network optimization portion of the Methodology for Areawide Planning Studies (MAPS) computer program. The development and calibration of the model are described in Appendix A. A map showing pipelines, well and storage tank locations, and data used in the model is provided in

Appendix B. The model was found to be very useful and will be given to the Government of Saipan to assist in future management of the system.

5. In this study, source and distribution alternatives were evaluated. Source alternatives are denoted by A1-A6 and are discussed in Part II. Distribution alternatives are denoted by D1-D4 and are discussed in Part III. This study determined which combination of source and distribution alternatives would provide a technically and economically feasible solution to Saipan's water system problems.

6. Also included in this report is an analysis of the recommendations for improving Saipan's water system contained in the report "Saipan Water Supply System Study" prepared by GK2, Inc./CE Maguire, Inc. (1982). The WES-developed computer model of the Saipan distribution network was used to evaluate the recommended changes to the system. A discussion of this analysis is given in Appendix C.

7. Results of the distribution modeling are presented in Appendix D. Future use of the Saipan distribution model is discussed in Appendix E. A summary of nomenclature for the alternatives evaluated in this study is given in Appendix F.

Description of System

8. The Saipan water system is operated as eleven separate subsystems although the subsystems are interconnected by valves which are normally closed. The water sources include wells pumping from basal, parabasal, and high-level groundwater aquifers and springs. The distribution lines are composed of various pipe material types. The poor condition of transmission lines, hydrant laterals, service lines, and storage tanks results in unusually high losses due to leaks. Currently no treatment processes are used except for chlorination at some points in the system. Chloride concentrations in some wells exceed the maximum concentration recommended by the Safe Drinking Water Act (Public Law 93-523) by a factor of six. Sodium may become a primary water quality standard because of the known health risks associated with ingestion. If sodium becomes a primary standard, it may be even harder for Saipan to meet the standards for water quality.

PART II: WATER BALANCE

9. This chapter will briefly describe the water resources on Saipan, potential sources for future development, and analyses of alternatives related to sources.

Water Resources

10. Water resources on the Island of Saipan have been investigated for three decades with increased interest in the last few years. Faced with problems of saltwater intrusion and depletion of existing sources, Saipan apparently needs additional resources to meet the water supply demand.

11. Groundwater is the predominant source of water on the Island of Saipan. Surface water resources are limited because of the limestone terrain that covers 90 percent of the island. The permeable nature of the geological formations makes surface runoff virtually negligible. There are stream flows over exposed volcanic areas, but the drainage basins are small, and thus stream flows are low (0.05 to 0.39 million gallons per day (MGD) for Talofofo Stream and 0.0 to 0.8 MGD for South Fork).* Lake Susupe is the largest of four natural lakes in the Mariana Islands. The lake is shallow, with a bottom elevation about 7 ft below sea level and a surface elevation of 1 ft above sea level. Contact with seawater results in high chloride levels for Lake Susupe. Development of existing surface water resources for water supply is reported to be unlikely and impractical (Barrett, Harris & Associated, Inc., and Sea Engineering, Inc. 1984).

12. Groundwater resources on Saipan are divided into three categories: (a) basal, (b) parabasal, and (c) perched or high level. Basal groundwater is defined as a lens of fresh water which is underlain by saltwater. Parabasal groundwater is in hydraulic continuity with the basal groundwater but not in contact with seawater because it is underlain by impermeable volcanic formations. Perched or high-level groundwater conditions result from percolating rainwater that is constrained by an impermeable formation (e.g. volcanic formations overlain with limestone). Most of the existing groundwater resources

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

developed for water supply on Saipan are found in basal and parabasal groundwater aquifers.

Existing sources for
water supply system

13. Most of Saipan's wells pump from basal and parabasal groundwater aquifers with flow rates in the range of 20 to 70 gallons per minute (gpm). Two wells, Maui I and IV, are infiltration galleries and produce more than 70 gpm (i.e., 315 and 335 gpm, respectively). Wells producing water from high-level groundwater regions are located in the areas of the Agag well field, Sablan Quarry, and the Calhoun Reservoir. Barrett, Harris & Associated, Inc., and Sea Engineering, Inc. (1984) reported that high production wells (i.e., pumping rates of 100 to 200 gpm) can be developed in these areas. Saipan's high-level groundwater resources also include Donni Springs, which flows from a limestone or limestone-volcanic formation lying on a less permeable layer of rock. The average flow from the springs is about 0.4 MGD (278 gpm), but it varies through the year from 35 to 350 gpm. The groundwater resources presently used in the Saipan water supply system are shown in Figure 1.

Water quality

14. The most serious water quality problems on the island of Saipan are high salinity levels, hardness, and total dissolved solids (TDS). The quality of groundwater resources is particularly threatened because of contamination resulting from migration of saltwater into the freshwater lens. Wells withdrawing water from the basal groundwater aquifers are the primary sources of chlorides measured within the distribution system. Wells in the basal groundwater regions are reported to produce water with chloride concentrations ranging from 400 to 5,000 mg/ℓ. These concentrations exceed the maximum concentrations recommended by the Safe Drinking Water Act of 250 mg/ℓ by a factor of two to twenty. High chloride levels have resulted in the abandoning of some wells in the basal and parabasal groundwater regions. Low salinity water is available from the high level groundwater wells and springs. High level groundwater wells produce water with chloride concentrations consistently below 250 mg/ℓ. In addition to problems of high salinity, Saipan also experiences problems with water hardness and high TDS levels. Many basal wells are reported to have greater than 500 mg/ℓ TDS which is the maximum concentration limit established by the Environmental Protection Agency's

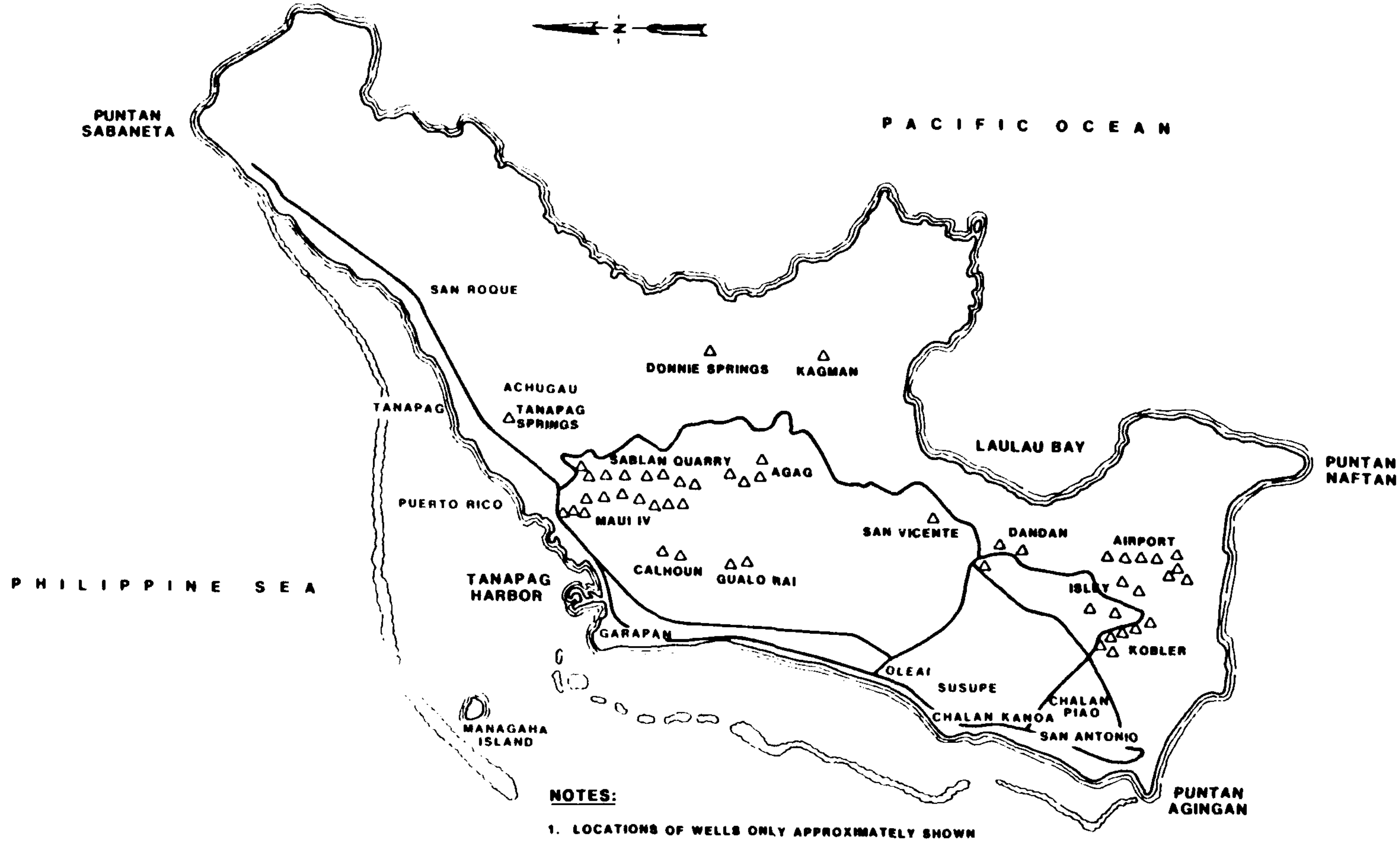

Figure 1. Existing wells used in the Saipan water supply system (Barrett, Harris & Associated, Inc., and Sea Engineering, Inc. 1984)

Secondary Standards. A high level of TDS affects the aesthetic quality of the drinking water. Some of the minerals and solids eventually precipitate and settle out and are deposited on water containers and other storage facilities. The combination of high levels of hardness and TDS encourages tuberculation of water pipes. This reduces the capacity of the distribution system network and shortens its useful life. Hardness can be reduced by water softening treatment. Two water softening plants have been constructed on Saipan, but have never been used.

Demand

15. For the Saipan system, water demand can be divided into two categories--municipal use and water lost to leakage. While an average of 85 to 145 gallons per capita per day (gpcd) is expected for a typical municipal system (including losses), the leakage on Saipan is so great that a per capita consumption rate as high as 245 gpcd has been reported by previous investigators. Less than 10 percent of the water system customers are metered. This makes it very difficult to determine actual consumption rates. There is some production rate data for sources, but the significant leakage problem makes it impossible to quantify the amount of water consumed and the amount of water lost to leakage. For the alternatives evaluated in this study, per capita consumption rates were estimated based on population, average consumption rates (GK2, Inc./CE Maguire, Inc. 1982), estimated commercial and institutional water use, and estimates of percent unaccounted-for water. Population projections for each village were provided by the POD and are given in Table 1. The service area boundaries of each village are shown in Figure 2. An estimate of the present day commercial and institutional water use is presented in Table 2.

16. Water use is expected to increase due to population growth and commercial development. It is imperative that the quantity of water lost to leakage be significantly reduced in order to meet this growing demand. Barrett, Harris & Associated, Inc., and Sea Engineering, Inc. (1984) reported that the 1984 water production on Saipan was about 5.0 MGD and consumption was 2.0 MGD. Therefore, approximately 3.0 MGD or 60 percent of water pumped from wells and springs was lost through leaks. Most municipal systems experience a 10 to 20 percent loss of water through minor leakage or unmetered use (e.g. fire fighting and mainline flushing). A reduction in leakage would reserve precious water resources for consumptive use and reduce pumping costs.

Table 1

Population Projections*

Service Area	Island Areas Included in Service Area**	Population Year 2000	Population Year 2040
Calhoun	Calhoun	1,300	1,600
Capitol Hill	Capitol Hill	1,200	1,600
Gualo Rai	Gualo Rai	600	1,000
Isley	San Antonio, Chalan Piao, Chalan Kanoa, Susupe, Oleai	9,700	10,100
Kagman	Kagman	600	900
Kobler	Kobler	2,300	2,600
Puerto Rico	Garapan, Puerto Rico	4,200	4,600
San Vicente	Dandan, San Vicente	2,000	2,400
Tasa	Tanapag, San Rogue	2,400	2,800
	Island Totals	24,300	27,600

* Population projections provided by POD (tourists not included).
** See Figure 2.

Table 2

Estimates for Commercial and Institutional Water Use*

Village		Average Daily Water Use, gpm Year 2000	Average Daily Water Use, gpm Year 2040
Isley		191	200
Puerto Rico		196	204
Tasa		0	54
	Island Totals	387	458

* Commercial and institutional uses include hotels, schools, and businesses; Source - Barrett, Harris & Associated, Inc., and Sea Engineering, Inc. (1984), and information provided by the Marianas' Visitor Bureau.

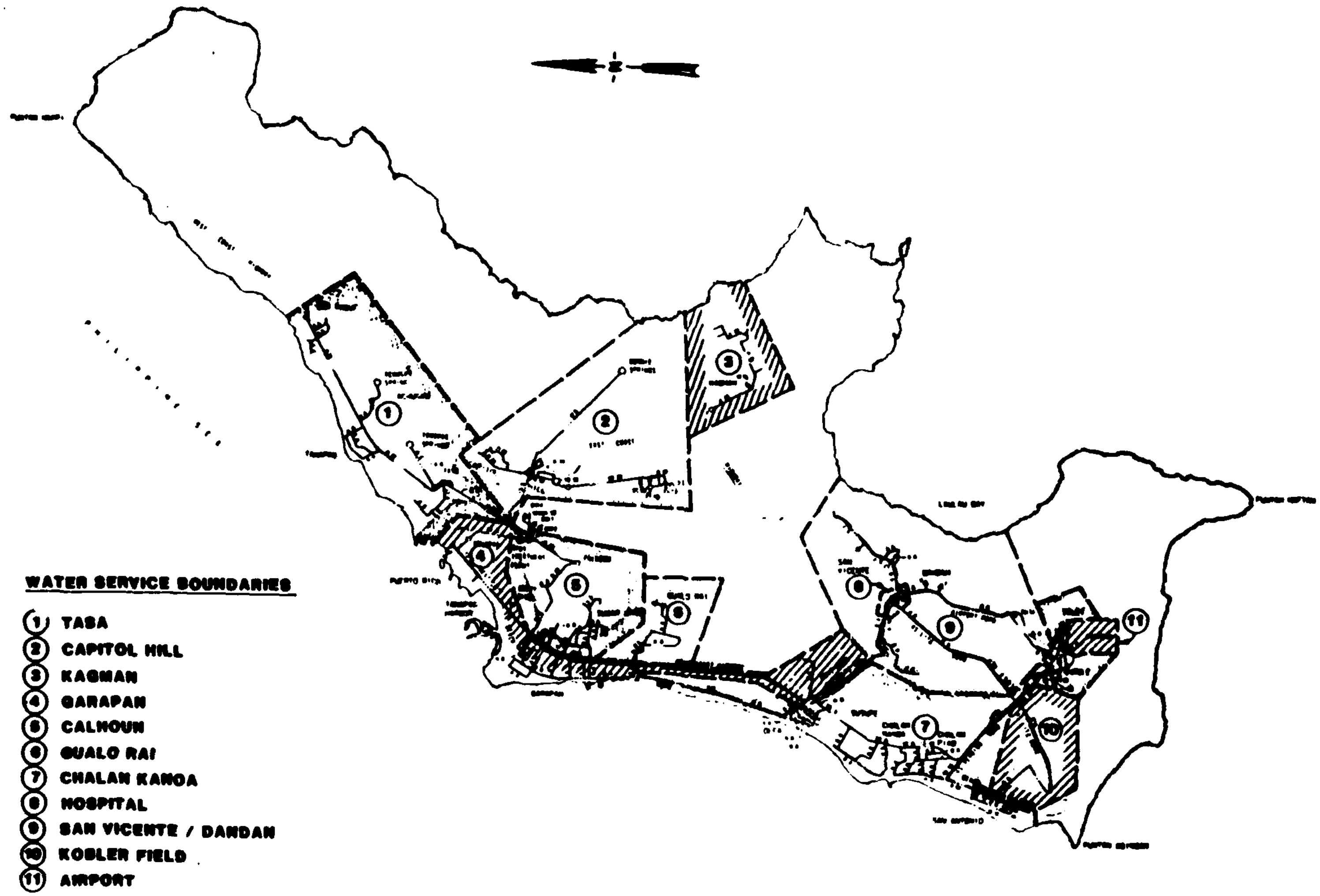

Figure 2. Water supply service areas on the Island of Saipan (Barrett, Harris & Associated, Inc., and Sea Engineering, Inc. 1984)

Potential Sources

Existing resources

17. In addition to continuing to use existing water supply sources, new sources to meet Saipan's growing water needs are being sought. The deteriorating water quality of several wells and the growing population demands projected for Saipan necessitate the exploration of new sources. The Honolulu Water Resources Division of the US Geological Survey (USGS) recently performed a study to locate and define boundaries of groundwater areas. These areas are shown in Figure 3. Potential area yields were estimated and are presented in Table 3. As previously discussed, the development of surface water sources (i.e., streams or lakes) is infeasible. However, a rainwater catchment basin has recently been constructed near the airport. Water will be collected from the surrounding 95 acres (approximate), pumped to the Isley Treatment Plant (presently under renovation), treated (filtration and chlorination), and then pumped to the distribution system. The water will be "blended" with high salinity water from the Kobler and Isley areas to reduce the overall chloride levels within the distribution system. The rainwater catchment basin is expected to yield about 350 gpm during the wet season and 90 to 140 gpm during the dry season. There are advantages and disadvantages to using this system for augmenting the water supply, and these factors have been discussed by earlier investigators (Barrett, Harris & Associated, Inc., and Sea Engineering, Inc. 1984; GK2, Inc./CE Maguire, Inc. 1982). The purpose of this study is not to evaluate the basin's relative merit but rather to evaluate it as part of the water system.

Water conservation

18. Water conservation measures have historically been practiced by water utilities on an emergency basis such as during prolonged droughts. In the past, Saipan has enforced limited water hours to conserve supplies. Other water conservation measures could also be implemented to achieve a reduction in water use. Examples include toilet leak repair, public education, shower flow restrictors, metering, toilet dams, etc. The success of conservation practices is measured by the reduction in water use or loss and is dependent on the public support and use of the conservation measures. A conservation program of metering and pricing policies can also be applied on the Island of Saipan. Water metering consists of monitoring and charging for water based

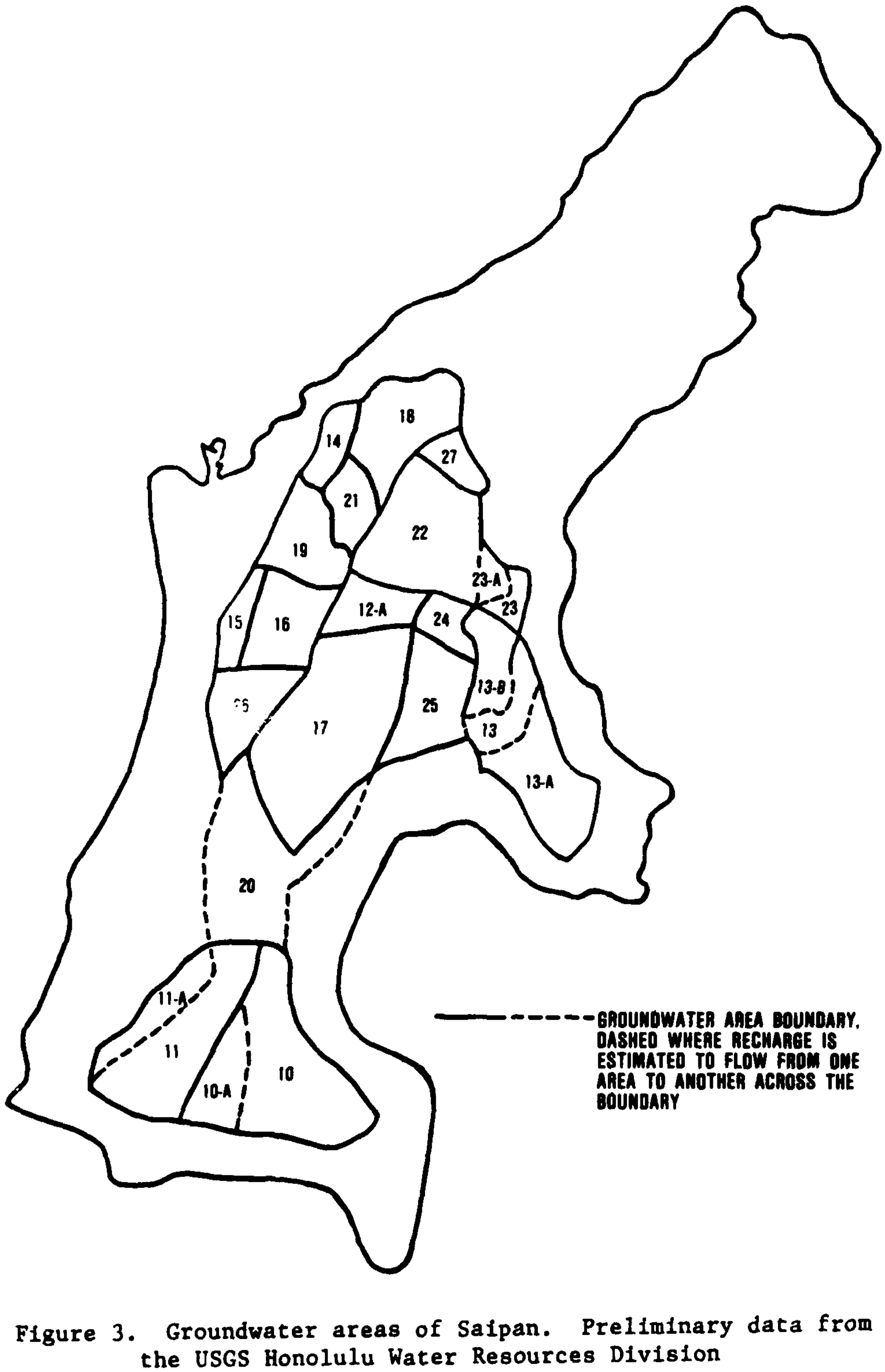

Figure 3. Groundwater areas of Saipan. Preliminary data from the USGS Honolulu Water Resources Division

Table 3

Groundwater Areas Identified by USGS*

Area Number	Area Name	Estimated** Potential Yield, gpm
10	Isley	278
13	Chacha	69
13A	Chacha	208
16	Takpachao	278
17	Etdot	694
19	Falipe	69
21	Rapugao	138
22	Denni	833
23	As Teo	138
24	Adilok	139
25	Papago	347
26	Taphla	138
27	Lisong	69

* Preliminary data from USGS Honolulu Water Resources Division.
** Above existing well production.

upon volume used by the customer. Since only 10 percent of the Saipan water customers are presently metered, a program of system-wide metering will function as a conservation program. A water rate study should be performed to establish the level for water prices. When a pricing policy is enforced, a significant water savings may be realized since customers will have to pay for the actual volume of water they use. Although the reduction in water use from implementing metering and pricing policies is probably small compared with leak repair, metering is necessary for accurately estimating water use rates. If system leaks are repaired, metering will provide information on the success of the leak repair effort. Also, a metering and pricing policies program will probably result in greater water savings than the other water conservation measures mentioned above.

Source-Related Alternatives

Alternative analysis

19. Six source-related alternatives were evaluated in this study. In investigating these alternatives, the effect of pipeline replacement is not considered. Alternatives involving significant improvements to the distribution system are discussed in Part III. The alternatives related to sources involve the use of existing sources, adding new sources, or adding new sources while abandoning poor quality sources. The effect of a major leak repair program is considered in three of the alternatives. The purpose of analyzing these source-related alternatives was to see if existing and/or potential sources will adequately meet future demands, if the repair of system leaks is necessary, and, if leak repair is required, to see if the repaired system will be adequate to meet future water needs. The alternatives related to water sources are briefly described as:

a. A1 - using existing sources, no leak repair.

b. A2 - using existing sources, leak repair.

c. A3 - adding new sources, no leak repair.

d. A4 - adding new sources, leak repair.

e. A5 - abandon poor quality wells, add new sources, no leak repair.

f. A6 - abandon poor quality wells, add new sources, leak repair.

20. Water loss rates used in the "leak repair" scenarios were based on the assumption that repairs would reduce water use rates to values generally

estimated for municipal systems (i.e., 80 to 140 gpcd). Leak repair was modeled by reducing the existing water demand to a per capita rate of 120 gpd (including unaccounted-for water). For alternatives without leak repair, the per capita water calculated when the distribution model was calibrated was used.

21. In Alternatives A3 through A6, new wells were added to service areas where existing sources could not meet the normal water use in the year 2040. The average daily demand was selected as the criteria against which sources were compared since water stored in tanks could provide water for peak usage and for fire fighting. Since there is no significant irrigation and no significant seasonal variation in water use due to tourist flux (i.e., tourism remains fairly constant through the year), daily water use is fairly constant throughout the year. The new wells were assumed to be drilled in the groundwater areas (i.e., those areas able to meet the required capacities) identified in the USGS study.

22. The water quality of Saipan's wells was evaluated, and wells with excessive chloride levels were assumed to be abandoned in Alternatives A5 and A6. Although the Safe Drinking Water Act recommends a 250-mg/ℓ maximum concentration limit for chlorides, only wells producing water with chloride concentrations of 500 mg/ℓ or more were abandoned. Thirty-seven percent of the existing wells were reported to produce water with chloride levels in excess of 1,000 mg/ℓ. The wells selected for abandonment and their pump capacities are listed in Table 4. The number of abandoned wells represents 46 percent of the existing wells.

Conclusions of each alternative analysis

23. Alternative A1. Alternative A1 corresponds to the existing Saipan water distribution system. No changes to the system were made since no leak repair and no pipeline replacement were assumed. An analysis of sources resulted in the data summarized in Table 5. The normal day water use (including water lost to leaks) is given in Table 5 for the years 2000 and 2040 for each service area. The capacity of the wells was taken at 80 percent of the rated capacity to account for downtime, repairs, and inefficient pumps. With no improvements to the Saipan water system, the existing sources will not meet the water demand in years 2000 and 2040. The total water deficit predicted for the island in the years 2000 and 2040 reinforces the fact that the existing system is grossly inadequate. A 3.9-MGD (2,688 gpm) deficit in 2000

Table 4

Wells Assumed to be Abandoned

Because of Poor Quality*

Village	Saipan Well No.	Model Node No.	Capacity, gpm	Chloride Content, mg/ℓ**
Kobler	116	173	25	
	10	132	45	1,684
	17	110	45	1,443
Isley	117	114	70	
	11	118	40	1,931
	15	122	75	1,404
	16	108	70	1,521
	Maui I	91	315	1,609
Puerto Rico	Maui IV	698	335	1,998
	144	514	45	1,648
	145	699	65	3,473
	163		70	1,669
	142	508	25	1,363
	143	512	50	2,765
	162	576	70	875
Calhoun	1	730	130	
	2	732	150	
Gualo Rai	152	365	50	973
	154	366	45	973
San Vicente	SV1	4	55	896
		Total Reduction in Capacity	1,775	

* Chloride concentrations > 500 mg/ℓ.

** Average chloride concentrations from data provided by the Saipan Department of Environmental Quality.

Table 5

Source Analysis for Alternative A1

Village	Water Demand, gpm Year 2000	Water Demand, gpm Year 2040	Well Capacity - Demand, gpm Year 2000	Well Capacity - Demand, gpm Year 2040
Calhoun	290	356	-66	-132
Capitol Hill	267	357	+205	+115
Gualo Rai	134	223	-58	-147
Isley	2,354	2,448	-1,610	-1,704
Kagman	134	201	-106	-173
Kobler	512	580	-420	-488
Puerto Rico	1,132	1,246	-28	-142
San Vicente	445	536	-161	-252
Tasa	536	624	-444	-532
		Total Water Deficit	-2,688	-3,455
			(3.87 MGD)	(4.98 MGD)

and a 5.0-MGD (3,455 gpm) deficit in 2040 are alarming. Analysis of alternative A2 shows how leak repair will improve the system based on a source/demand comparison.

24. Alternative A2. A water use rate of 120 gpcd was used in Alternative A2 assuming leak repair of the existing system. A comparison of yields from the sources and the projected demands resulted in the data summarized in Table 6. Water demand and well capacity are the same terms as defined for Table 5. Under the assumed conditions (i.e., 120 gpcd use and using existing sources), four of the nine service areas are predicted not to meet demands in the year 2000, and five are predicted not to meet demands in the year 2040. These localized shortages can be met by transferring water between villages. Because there is a net surplus of 704 gpm (or 1 MGD) on the island in the year 2000 and 341 gpm (or 0.5 MGD) in the year 2040, repairing distribution system leaks will protect Saipan's overall water supply. In areas where a water deficit is predicted, additional sources must be developed or service areas must be effectively interconnected. The value of adding additional sources was analyzed in Alternatives A3 through A6 and will be discussed in subsequent paragraphs. Connecting service areas involves system changes and is discussed

Table 6

Source Analysis for Alternative A2

Village	Water Demand, gpm		Well Capacity - Demand, gpm	
	Year 2000	Year 2040	Year 2000	Year 2040
Calhoun	108	134	+116	+90
Capitol Hill	100	134	+372	+338
Gualo Rai	50	84	+26	-8
Isley	1000	1042	-256	-298
Kagman	50	75	-22	-47
Kobler	192	216	-100	-124
Puerto Rico	546	604	+558	+500
San Vicente	166	200	+118	+84
Tasa	200	286	-108	-194
		Total Water Surplus	+704	+341
			(1.01 MGD)	(0.49 MGD)

in Part III. Of particular concern in Alternative A2 is the adequacy of water supply in the villages of Isley, Kobler, and Tasa to meet future demands. As the largest user of water, Isley must not only supply residential customers but also hotels in the service area. Since tourism is Saipan's most important income-producing industry, it is imperative that the water supplies in the future are available for both residential and commercial users. A hotel is presently proposed for construction in the Tasa service area. Even if leaks are repaired, existing sources will not be able to meet the demands placed on the system by this hotel and the growing population unless new sources are developed or system improvements to bring water from other villages are made. The new Koblerville subdivision in the Kobler area places this system in a similar predicament requiring additional improvements beyond leak repair.

25. Alternative A3. The same water demands used in Alternatives A1 and A2 were used for Alternatives A3 and A4, respectively. Both Alternative A3 and A4 involved adding new sources to meet future demands. In addition, Alternative A4 included leak repair. Each service area was evaluated for its capability to meet the normal day use, year 2040. Individual service areas were evaluated separately since it is the current practice to operate separate

systems. Major operational changes (e.g., connecting service areas) are discussed in Part III. Table 7 lists the service areas requiring additional sources to meet future demands, the additional quantity needed, and the USGS groundwater area selected to supply the additional water for Alternative A3. Where additional resources could not meet the demand, the value in the last column of Table 7 represents the quantity of water unavailable from the existing and potential sources. In Alternative A3, a total of 3,570 gpm or 5 MGD of water above existing source capacity is required to meet future demands if system leaks are not repaired. Using the preliminary data provided by the USGS, the potential yield of the groundwater areas was distributed to each of the service areas needing additional sources in the year 2040. The deficit of 172 gpm could be met by the rainwater catchment basin which is expected to yield from 90 to 350 gpm. Approximately 45 wells will have to be drilled assuming a production rate of 75 gpm each. At a cost of $52,000 per well,* approximately $2.34 million would be required to drill enough wells to meet Saipan's water needs without leak repair. Along with the cost of drilling new wells, approximately 91,400 ft of transmission lines would have to be laid at an approximate cost of $2.5 million based on 6-in. polyvinyl chloride (PVC) pipe at $27 per lin ft. Although the numbers in Table 7 show that the water demand in 2040 can be met by potential groundwater yields and the rainwater catchment basin, it is not recommended that the island operate its water system to the limit of its available water resources. Also, the impact of the basin on the recharge of the underlying groundwater aquifer has not been evaluated.

26. Alternative A4. Alternative A4 improves the distribution system over Alternative A3 by including leak repair. By repairing the leaks in Saipan's system, the quantity of water required in excess of existing sources was reduced from 3,570 gpm in Alternative A3 to 671 gpm in Alternative A4 (see Table 8). Only nine new wells would have to be drilled and 20,400 ft of transmission lines laid at an estimated cost of $468,000 for the wells and $550,000 for the pipelines. The potential groundwater yield estimated by the USGS is sufficient to meet Saipan's needs in 2040 under the assumptions of Alternative A4. Because fewer new wells are needed, they can be drilled near

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* New well cost (GK2, Inc./CE Maguire, Inc. 1982) updated to March 1985 dollars.

Table 7

Source Analysis for Alternative A3

Village	Quantity of Water Required* Above Existing Sources, gpm	Quantity of Water (gpm) Provided By Indicated Potential Groundwater Source Area**													Total Quantity of Water Provided by Potential Sources, gpm	Quantity of Water Not Provided by Existing and Potential Sources, gpm
		10	13	13A	16	17	19	21	22	23	24	25	26	27		
Calhoun	132				23		69								92	40
Gualo Rai	147				147										147	0
Isley	1,704			104	108	232			370	138	139	347	138		1,576	128
Kagman	173		69	104											173	0
Kobler	488	278				210									488	0
Puerto Rico	142							138							138	4
San Vicente	252					252									252	0
Tasa	532								463					69	532	0
Totals	3,570	278	69	208	278	694	69	138	833	138	139	347	138	69	3,398	172
															(4.89 MGD)	(0.25 MGD)

* Normal day use, year 2040.

** Preliminary data from USGS Honolulu Water Resources Division. See Table 3 for groundwater area names and potential yields.

Table 8

Source Analysis - Alternative A4

Village	Quantity of Water Required* Above Existing Sources, gpm	Quantity of Water (gpm) Provided By Indicated Potential Groundwater Source Area**													Total Quantity of Water Provided by Potential Sources, gpm	Quantity of Water Not Provided by Existing and Potential Sources, gpm
		10	13	13A	16	17	19	21	22	23	24	25	26	27		
Gualo Rai	8				8										8	0
Isley	298	154				144									298	0
Kagman	47		47												47	0
Kobler	124	124													124	0
Tasa	194								194						194	0
Totals	671	278	47	0	8	144	0	0	194	0	0	0	0	0	671	0
															(0.97 MGD)	

* Normal day use, year 2040.

** Preliminary data from USGS Honolulu Water Resources Division. See Table 3 for groundwater area names and potential yields.

(less than 2 miles) the service areas needing the water, thus reducing the total length of pipelines required to connect the sources to the system. Other problems still exist however, the most significant being water quality. With the continued use of existing sources, high chloride content water will remain a problem.

27. Alternative A5. In Alternatives A5 and A6, the impact of abandoning poor quality wells on the available quantity of water was investigated. The same water demands as Alternatives A3 and A4 were assumed for Alternatives A5 and A6, respectively. In this analysis, existing wells producing water with chloride concentrations in excess of 500 mg/ℓ, as shown in Table 4, were assumed abandoned. The capacity, above existing source production rates, required to meet the normal day use for year 2040 can be provided by adding new wells. Table 9 lists the service areas requiring additional sources in Alternative A5, the additional quantity needed, and the USGS groundwater area selected to supply the additional water. If wells producing water with excessive chloride concentrations are abandoned, an estimated 5,345 gpm or 7.7 MGD of water will be required, above existing well production, to meet the normal day use, year 2040. However, only 3,398 gpm or 4.9 MGD has been estimated by the USGS as potential yield above the current well production rates. This leaves a water shortage of 1,947 gpm or 2.8 MGD. The inability of Alternative A5 to meet future demands makes it infeasible.

28. Alternative A6. Future water demands can be met, however, by Alternative A6 assuming the repair of system leaks and adding new wells. Table 10 shows that the estimated potential yield of untapped groundwater resources is sufficient to meet water use requirements in 2040 when poor quality wells are abandoned. Approximately 22 new wells are required to meet water demands above the existing well production minus the wells assumed abandoned. At $52,000 per well, a cost of $1.14 million is estimated for providing enough water from groundwater sources. Approximately 50,200 ft of transmission lines would be laid to connect the new wells to the existing distribution system. The cost of these lines is estimated at $1.36 million.

Summary of source analyses

29. Analyses of Alternatives A1 through A6 show that adding new sources and repairing system leaks are necessary to make Saipan's water system adequate for future needs. Leak repair will help protect Saipan's water sources from depletion by reducing the amount of water pumped into the system

Table 9

Source Analysis - Alternative A5*

Village	Quantity of Water Required** Above Existing Sources, gpm	Quantity of Water (gpm) Provided By Indicated Potential Groundwater Source Area†													Total Quantity of Water Provided by Potential Sources, gpm	Quantity of Water Not Provided by Existing and Potential Sources, gpm
		10	13	13A	16	17	19	21	22	23	24	25	26	27		
Calhoun	412				23		69								92	320
Gualo Rai	242				147										147	95
Isley	2,274			104	108	232			370	138	139	347	138		1,576	698
Kagman	173		69	104											173	0
Kobler	603	278				210									488	115
Puerto Rico	802							138							138	664
San Vicente	307					252									252	55
Tasa	532								463					69	532	0
Totals	5,345	278	69	208	278	694	69	138	833	138	139	347	138	69	3,398	1,947
															(4.89 MGD)	(2.80 MGD)

* See Table 4 for list of wells assumed abandoned.
** Normal day use, year 2040.
† Preliminary data from USGS Honolulu Water Resources Division. See Table 3 for groundwater area names and potential yields.

Table 10

Source Analysis - Alternative A6*

Village	Quantity of Water Required** Above Existing Sources, gpm	Quantity of Water (gpm) Provided By Indicated Potential Groundwater Source Area†													Total Quantity of Water Provided by Potential Sources, gpm	Quantity of Water Not Provided by Existing and Potential Sources, gpm
		10	13	13A	16	17	19	21	22	23	24	25	26	27		
Calhoun	280				67	144	69								280	0
Gualo Rai	103				103										103	0
Isley	868					550						318			868	0
Kagman	47		47												47	0
Kobler	239	239													239	0
Puerto Rico	160							138	22						160	0
Tasa	194								194						194	0
Totals	1,650	239	47	0	170	694	69	138	216	0	0	318	0	0	1,650	0
															(2.38 MGD)	(0 MGD)

* See Table 4 for list of wells assumed abandoned.
** Normal day use, year 2040.
† Preliminary data from USGS Honolulu Water Resources Division. See Table 3 for groundwater area names and potential yields.

and protecting the aquifer from overpumping and eventual breakdown of the freshwater/saltwater boundary. A problem may be experienced, however, in the basal groundwater area if leaks are repaired. If the system no longer leaks and consequently does not contribute to the recharge of the aquifer, basal well yields may be reduced.

30. For the leak repair scenarios (A2, A4, A6), a pilot study is recommended to first determine the severity of the problem and to locate leaks which need repair in a few small areas. This study should include a sonic leak detection analysis and an examination of sample sections of pipe. The study should include examining pipe sections in every village and of every type of pipe material for leaks. The cost of a pilot study is estimated at $20,000 for sonic leak detection and $20,000 for examination of some sample buried pipe sections and joints. The pilot study will indicate if leak repair is economical or if the system should be replaced. For example, if the pilot study concludes that 10 percent of the system suffers breaks and must be repaired, the cost of repair may be on the order of $2 million based on repair costs of $1,000 per break. However, if 70 percent of the system needs repair, a cost of approximately $12 million is estimated. Only a leak detection survey can identify the magnitude of the repairs needed and hence the expected costs. It is important to note that leak repair will save pumping energy costs and this should be considered in an overall cost analysis.

31. Adding new wells will be necessary in areas where existing sources cannot meet future demands. If system leaks are repaired, new wells will only be added as needed to meet growth. It is necessary to consider abandoning poor quality wells since many wells are producing water with a chloride content in excesses of 1,000 mg/ℓ, more than four times the maximum concentration recommended by the Safe Drinking Water Act (SDWA). Even abandoning wells with chloride concentrations greater than 500 mg/ℓ, rather than meeting the SDWA's recommendation of 250 mg/ℓ, creates a water shortage of 1,775 gpm. New wells in higher areas will be necessary to cover this shortage and to meet future demands. Eventually abandoning wells in basal areas could improve water quality in these areas.

32. Existence of surplus water in the year 2040 is predicted for the villages of Calhoun, Capitol Hill, Puerto Rico, and San Vicente in Alternative A4 and Capitol Hill and San Vicente in Alternative A6. Connecting some service areas could make this water available to water-short areas and thus

decrease the number of new wells needing to be developed. Connection of service areas is discussed in Part III.

33. Estimated costs in millions of dollars for Alternatives A1 through A6 are summarized in Table 11. Costs are given for new wells, pipeline to connect new wells with the existing distribution system, and leak repair. A range of costs is given for the leak repair scenarios since the nature of the leaks and the magnitude of the repair work are unknown at this time. Several factors must be considered when comparing these alternatives. These include the magnitude of leak repair costs (which cannot be determined without a leak detection study), the feasibility of connecting service areas (to distribute the surplus water to water-short areas), and whether or not poor quality wells must be abandoned. Alternative A1 is obviously infeasible because of its inadequacy to meet future demands. Alternative A2 will only be feasible if water is transferred from water-surplus areas to water-short areas, requiring some service area interconnection. By including the rainwater catchment basin, Alternative A3 will become feasible, comparing supply and demand, but the available water resources will be pumped to their limit. Alternative A4 which consists of Alternative A3 plus leak repair will provide adequate water although water quality will remain poor. If poor quality wells have to be abandoned, only Alternative A6 can be considered from this set of alternatives.

Table 11

Cost Summary of Sources Analysis

Alternative*	Costs, in millions of dollars				Net Water Supply, Year 2040	
	New Wells	Pipeline	Leak Repair	Total	gpm	MGD
A1	0	0	0	0	-3,455	-4.97
A2	0	0	2-12	2-12	+341	+0.49
A3	2.3	2.5	0	5	-172	-0.25
A4	0.5	0.6	2-12	3-13	+1,012	+1.46
A5	2.3	2.5	0	5	-1,947	-2.80
A6	1.1	1.4	2-12	5-15	+422	+0.61

* A1 - existing sources, no leak repair.
A2 - existing sources, leak repair.
A3 - adding new sources, no leak repair.
A4 - adding new sources, leak repair.
A5 - adding new sources, abandon poor quality wells, no leak repair.
A6 - adding new sources, abandon poor quality wells, leak repair.

PART III: DISTRIBUTION NETWORK IMPROVEMENTS

34. Additional source development will result in the need to modify the distribution system to get water to users. These modifications and the operational scheme of the Saipan water system will be discussed in this section. First, the existing network and system problems will be described briefly. Network changes to make the system sufficient for future needs will then be discussed based on the existing system with existing operations and with improved operations. Two other alternatives, complete replacement of the system and a dual water system, will also be discussed. A summary of the four distribution alternatives will be given. Analyses of distribution modeling are given in Appendix D.

Existing Distribution System

35. The water distribution system on the Island of Saipan consists of eleven separate service areas (Barrett, Harris & Associated, Inc., and Sea Engineering, Inc. 1984 and GK2, Inc./CE Maguire, Inc. 1982) as shown in Figure 2. Each area is a network of distribution lines with a common pressure source. This study evaluated nine of these pressure zones (listed in Table 1), eliminating the hospital and airport areas because they are small and do not serve residential customers. The existing system is made up of various materials (e.g. concrete, cast iron, asbestos cement). Eleven storage tanks having a combined capacity of 5.6 million gallons serve the nine service areas. This storage capacity is approximately equal to a 1-day supply of water. No water treatment processes are currently used except for the addition of gaseous chlorine as a disinfectant to the supply at some wells and reservoirs. The water collected at the rainwater catchment basin will be treated by filtration and chlorination. More details on the Saipan infrastructure can be found in Barrett, Harris, & Associated, Inc., and Sea Engineering, Inc. (1984) and GK2, Inc./CE Maguire, Inc. (1982).

Existing System Problems

36. Source inadequacy (both quantity and quality), excessive leakage, inefficient pumps, and the need for hands-on valve operation are the major

problems of the Saipan water system. Source-related problems have been discussed in Part II. Distribution system problems have been described in earlier reports (Barrett, Harris, & Associated, Inc., and Sea Engineering, Inc. 1984 and GK2, Inc./CE Maguire, Inc. 1982) but are summarized here.

37. Losses through leakage are excessive from various distribution components including mains, hydrant laterals, storage tanks, and service lines. Excessive mainline pressures occur in the Mihaville subdivision served by lines from the Calhoun area. Elevations in the Mihaville subdivision are less than 100 ft while the floor elevation of the Calhoun Reservoir is at 540 ft. A pressure reducing valve (PRV), intended to maintain pressures within normal ranges (60 to 80 psi), has been improperly set and results in plumbing fixture leakage and excessive pressures (greater than 100 psi) within the distribution system. Leakage is believed to be a problem in all nine systems. According to Department of Public Works (DPW) officials, an annual budget of less than $20,000 (not including salaries) is allotted for operation and maintenance (Barrett, Harris, & Associated, Inc., and Sea Engineering, Inc. 1984). This is not sufficient to properly maintain the system.

38. The GK2, Inc./CE Maguire, Inc. (1982) study reported that approximately 20 percent of the pumps were found to be pumping at rates 60 percent or less of the manufacturer's rated pumping capacity. Over one third of all pumps needed repair. The inadequate budget of the DPW makes it impossible to properly maintain these pumps. Historically, when a pump fails, it is out of service for several weeks waiting for parts and service.

39. Currently several valves have to be manipulated by DPW employees to make the water system function adequately in all service areas. This operational practice is labor-intensive, involving daily spot checks of pressures throughout the system and manipulation of system valves.

Alternatives for the Distribution System

40. Four distribution alternatives will be discussed:

a. D1 - existing system with existing operations.

b. D2 - existing system with different operations.

c. D3 - complete replacement of system.

d. D4 - a dual system.

Each distribution alternative will be discussed as it relates to one or more

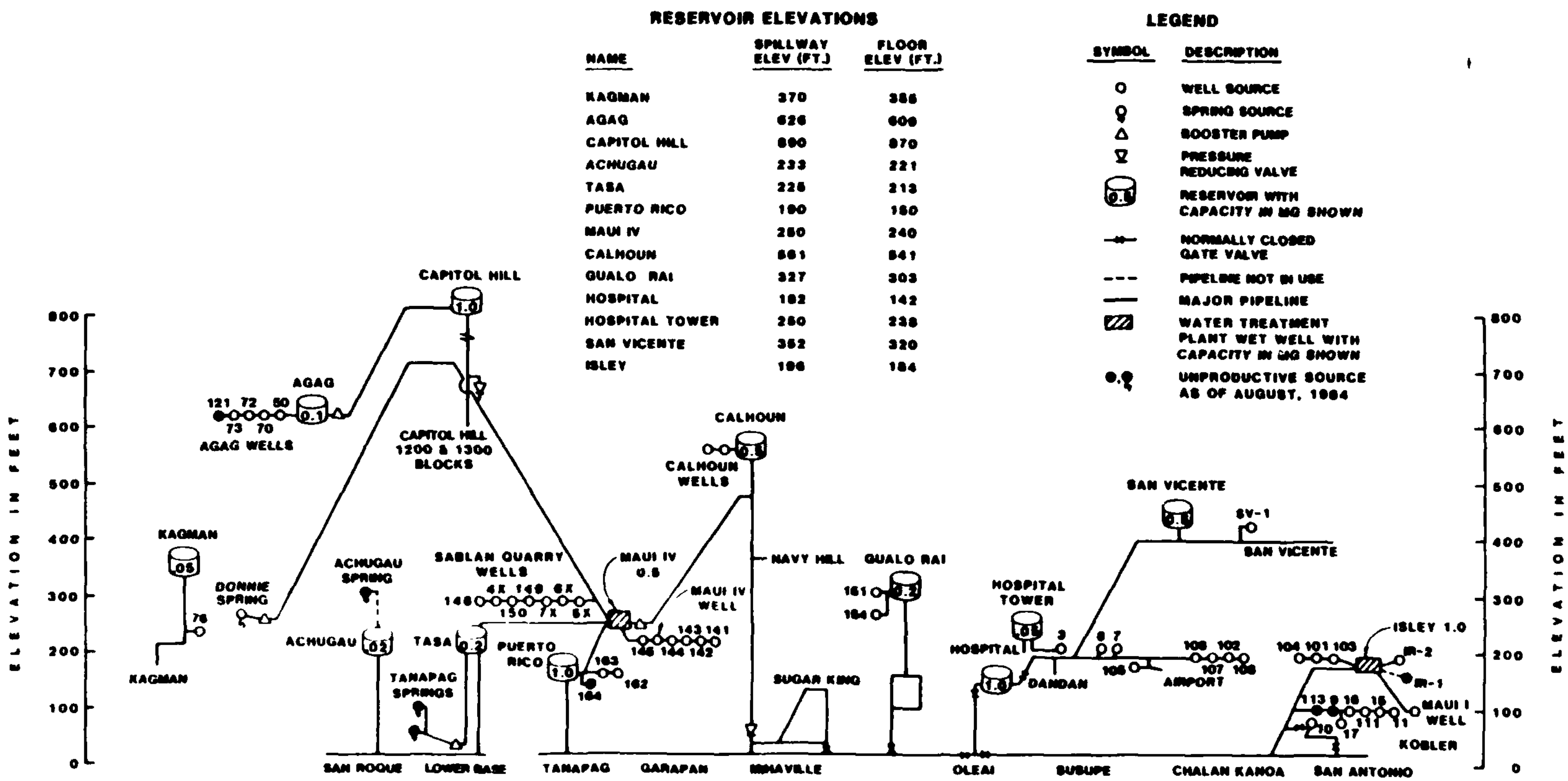
of the source alternatives presented in Part II. Source alternatives A1 and A5 will not be considered since they cannot meet future demands on the system. Given that enough water is provided by Alternatives A2, A3, A4, and A6, distribution improvements required to make the system operable will be discussed.

Alternative D1 - Existing system and operations

41. This section describes some changes to the distribution network while making no changes in the current operation practices. The changes primarily involve the laying of transmission lines for carrying more water to areas not predicted to meet average day demands in 2040. A profile of the existing system is shown schematically in Figure 4. The current practice of operating the system as separate subsystems is illustrated by the gate valves shown in Figure 4 as normally closed. Costs associated with these alternatives include the cost for the source-related alternatives plus approximately $0.5 million for a storage tank in Kobler.

42. Alternative A2. Although Alternative A2 (leak repair only) shows a surplus of water available, some service areas are not predicted to meet system demands in 2040. Therefore, manipulation of system valves will be necessary to transfer water from water-surplus areas to water-short areas. Water will be needed in the southern portion of the island in the Isley and Kobler areas. The Puerto Rico service area is the most likely candidate for supplying water to this area. The valves which close off the Isley and Kobler systems from the Puerto Rico area will have to be regulated to allow water into the Isley and Kobler areas. The surplus water in Capitol Hill area will have to be collected in the Maui IV distribution box and used by the Tasa system, which has been predicted to be short of 2040 demands by 194 gpm. This alternative will require frequent adjustment of system valving, which is labor-intensive.

43. Alternative A3. Sources are added to meet water system demands in Alternative A3. The need for additional water in Isley will also require manipulation of existing valves to transport the water from the Capitol Hill area via the Maui IV distribution box and the Puerto Rico service area to the Isley service area. New transmission lines will be required to transport water to the systems needing additional water from new wells. In the Calhoun area, 6-in. transmission lines will be necessary from the new wells to the Calhoun storage tanks. The PRV at the bottom of Navy Hill will have to be



RESERVOIR ELEVATIONS

NAME	SPILLWAY ELEV (FT.)	FLOOR ELEV (FT.)
KAGMAN	370	355
AGAG	626	606
CAPITOL HILL	890	870
ACHUGAU	233	221
TASA	225	213
PUERTO RICO	190	150
MAUI IV	250	240
CALHOUN	561	541
GUALO RAI	327	303
HOSPITAL	182	142
HOSPITAL TOWER	250	238
SAN VICENTE	352	320
ISLEY	196	184

Figure 4. Schematic hydraulic profile of the existing Saipan water system (Barrett, Harris & Associated, Inc., and Sea Engineering, Inc. 1984

properly set to maintain pressures in the Mihaville area in the range of 60 to 80 psi.

44. In Gualo Rai, Kagman, and Puerto Rico a 6-in. transmission line will transport water from the new wells to the storage tanks serving each area. San Vicente, however, will need a new parallel transmission line, 8 to 10 in. in diameter, to transfer the needed extra 252 gpm from USGS groundwater area 17 (see Figure 3) to the San Vicente distribution area. Likewise, larger mains will be needed to transport water to the Tasa system from the new well locations in USGS groundwater area 22. The Kobler service area will require a storage tank and larger mains to carry the needed 488 gpm from new wells to the area. The 8-in. lines which were laid in the newly constructed Koblerville subdivision should be adequate for future needs. A storage tank is necessary in the Kobler area if it is to continue to operate as a separate system. The tank will provide water to meet demands for peak flows and fire fighting.

45. Alternative A4. By adding sources and repairing leaks, the nine service areas can continue to operate individually. Six-inch transmission lines will be necessary to transfer water from the new well locations to the storage tanks in Gualo Rai, Isley, Kagman, Kobler, and Tasa. A storage tank is required in the Kobler area if it is to continue operating as a separate system.

46. Alternative A6. The changes mentioned for Alternative A4 are also required in Alternative A6. Because more new wells are being added, due to the abandonment of poor quality wells, transmission lines larger than 6 in. will be needed to transport large flows (greater than 350 gpm) from newly developed well fields in USGS groundwater areas 17 and 25 to the water-short villages (i.e., Isley) which have been relying on the basal aquifer.

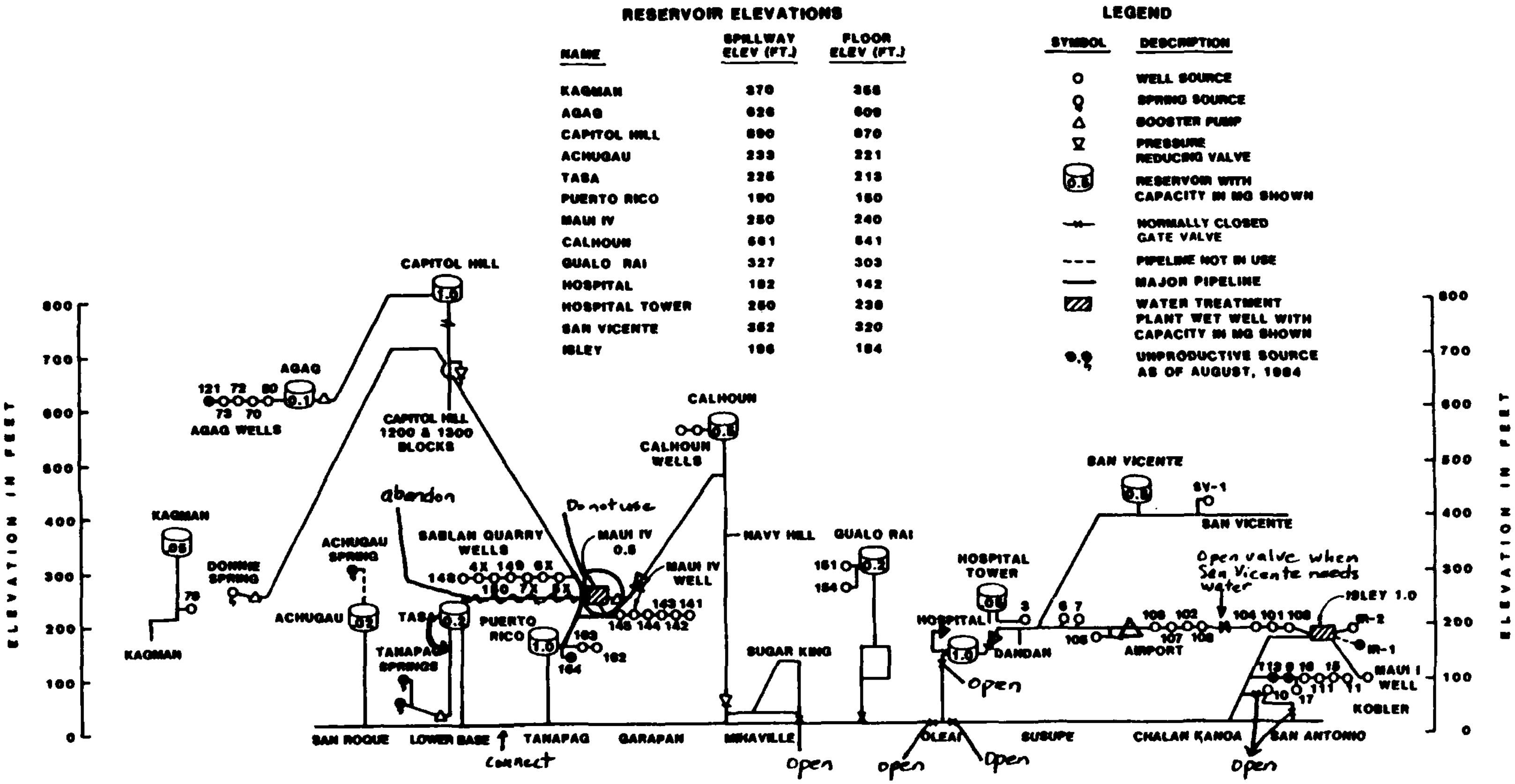
Alternative D2 - Different operations

47. A simpler operating scheme involving the interconnection of two or more systems of similar pressure zones should reduce the need for much of the hands-on operation of valves in the Saipan water system. Interconnection of a few of the individual systems or connection of the entire Saipan water system offers an advantage in that the system will operate by itself as a few pressure zones. Because of the elevation differences between the existing systems, it will not be possible to operate all of the existing systems as one

pressure zone. When two zones with markedly different elevation are connected and the water source is located in the higher zone, the zones should be connected by a pressure-reducing-sustaining valve which will allow water to flow to the lower zone if there is adequate water in the high zone and pressure is low in the low zone. If the source is in the lower zone, the lower zone will feed the higher zone through a booster pump. It will also be necessary to change the elevation of storage tanks so that all the tanks within the interconnected system operate at the same head.

48. A modified version of Figure 4 appears as Figure 5 showing the changes which can be made to connect some of the subsystems. One change involves connecting the service areas of Tasa, Puerto Rico, Calhoun, and Isley by opening the valves which normally close off these areas from one another. In addition, the Tasa storage tank will have to be lowered and the Hospital Reservoir (which serves the Puerto Rico area) raised to the same elevation as the Puerto Rico tank so that the interconnected system can operate from one hydraulic grade line. Pressure-reducing-sustaining valves will be necessary between Calhoun and Puerto Rico and Calhoun and Mihaville to ensure acceptable downstream pressures and to prevent the upper Calhoun system from draining. The Maui IV wet well should not be used but rather the water from Donni Springs and Sablan Quarry wells should be allowed to flow directly into the Puerto Rico tank. An electronic shut-off system could be installed at Donni Springs so that when the Puerto Rico tank is full the pumps at Donni Springs would shut off. Because water hammer can cause damage to long pipelines where the flow is stopped abruptly, some measures should be taken to prevent this damage in the line connecting Donni Springs and the Puerto Rico tank. To avoid water hammer damage, positively controlled valves should be used to control surge pressures during normal operation and in the event of power failure. These valves control the change in flow velocity, thus preventing flow from stopping abruptly (except during a power failure). An air valve could be placed at the highest point along the Donni Springs line to prevent the creation of a vacuum and column separation due to a pressure surge. Air valves limit pressure surges by allowing air to enter the pipeline to prevent column separation.

49. A pressure-reducing-sustaining valve between Dandan and the Hospital Reservoir will allow water to flow from San Vicente to the Puerto Rico/Isley area if the pressures of the low elevation zone are too low. If the



RESERVOIR ELEVATIONS

NAME	SPILLWAY ELEV (FT.)	FLOOR ELEV (FT.)
KAGMAN	270	266
AGAG	626	606
CAPITOL HILL	690	670
ACHUGAU	233	221
TASA	226	213
PUERTO RICO	190	180
MAUI IV	250	240
CALHOUN	661	641
GUALO RAI	327	303
HOSPITAL	182	142
HOSPITAL TOWER	260	238
SAN VICENTE	362	320
ISLEY	196	184

Figure 5. Schematic hydraulic profile of the Saipan water system showing interconnection of some subsystems

poor quality wells now serving San Vicente from the Isley well field are abandoned, the new booster pump located in the Isley well field will have to be used to pump water from the Isley Reservoir to San Vicente. This operation will require opening the valve which currently closes off the Isley system from the San Vicente system. San Vicente will receive better quality water from the Isley Reservoir when the rainwater catchment basin is brought on-line. Isley will continue using water from the rainwater catchment basin, the Isley well field, the Puerto Rico area, and, if necessary, new well fields.

50. Gualo Rai and Kagman can continue to operate separately. New wells from nearby groundwater aquifers (see Part II of this report) will have to be drilled to meet future water needs. The Capitol Hill area will continue to be served by the Agag well field. A pressure-reducing-sustaining valve between the Capitol Hill and Donni Springs line should be installed and set so that when Donni Springs is not used (e.g., during the dry season or drought conditions) and water is needed in the Puerto Rico area, the valve will open and allow water to flow from Capitol Hill to the low elevation zone. A check valve will be needed to prevent water from Capitol Hill from flowing to Donni Springs.

Alternative D3 - Complete replacement

51. Replacement of the entire distribution system on Saipan would involve installing approximately 60 miles of distribution pipeline. At least 6-in.-diam pipe should be used to ensure adequate fire protection. Service lines to the approximately 3,300 customers should be replaced with 3/4-in. (or greater if necessary) PVC or copper pipe. Complete replacement would require a redesign of the system to optimize pipe sizes and to create a handful of pressure zones instead of the existing eleven. The system will be made up of one low zone and several small high zones. A discussion of the interconnection of some subsystems is presented under Alternative D2. A profile of elevations of this proposed system is shown schematically in Figure 5. All the storage tanks in low coastal areas should be designed at the same elevation so that the low zone system operates by itself on one hydraulic grade line. Pressure-reducing-sustaining valves will be needed to control pressures in the low zone. The valves will be set so that they are normally closed but will open if emergency flows are needed in the low zone and water is available in the higher zones. Some booster pumping may be required for the higher areas

(e.g. Calhoun, San Vicente) depending upon the elevation of the hydraulic grade line. Operating the water distribution network as one system will save operating costs. A cost of approximately $15 million is estimated for complete replacement using existing sources. Another $1 million is required if new well sources are added or another $2.5 million if new well sources are added and poor quality wells are abandoned.

Alternative D4 - Dual system

52. In dual water systems, two grades of water, potable and subpotable, are supplied to consumers through separate distribution systems. Potable water may be defined as water that is safe for long-term continuous human ingestion and should satisfy drinking water regulations of the SDWA. Subpotable water may be defined as water that is bacteriologically safe but is not safe for long-term continuous human ingestion. Since the fraction of water use for drinking water is relatively small on Saipan, a small distribution system, primarily 2-in. PVC pipe, can carry potable water. Treatment processes, such as filtration and chlorination, will be required to provide water which satisfies the SDWA regulations. The existing system can carry subpotable water for fire protection and nondrinking water purposes. A dual system on Saipan would require a smaller network of 2-in. PVC pipe (larger diameter pipe may be required for some lines), a water treatment facility, storage facilities, replacement of existing service lines, and repair of leaks in the existing distribution system. A cost of approximately $12 million is estimated for a dual system with an additional $2 to $12 million for leak repair in the existing system. This cost estimate does not include the cost of modifying the existing water systems within buildings. The existing system will become a subpotable system for fire fighting and nondrinking water purposes. In areas in which leakage is excessive, repair is costly, and no high valued properties are located (e.g. hotels, industries), the existing system will be abandoned and fire protection will not be provided. This is typical of many rural systems.

53. As an alternative to repairing leaks, the old system could only be used during fires by using ground storage tanks. The leaks would not need to be repaired since the system will only be under pressure when the fire fighting pumps are on. Diesel powered pumps, although more expensive, could be used instead of electrically driven pumps since they will only be used during fires and will continue to provide fire protection during power outages.

Periodic operation of the diesel driven pumps would be required for good maintenance. Ground storage tanks would be placed at various locations throughout the more populated portions of the island (e.g. Capitol Hill, Kobler, Isley, and Puerto Rico) and would be kept full at all times with the outlet valve closed. The tanks will be filled from the basal wells through the old distribution system. The Insurance Service Office (1980) considers a fire flow to be 1,500 gpm for a duration of 2 hr for areas with one- and two-family dwellings not exceeding two stories in height. For other buildings, up to 3,500 gpm maximum for a duration of 3 hr is recommended. Therefore, in the areas of Kobler and Capitol Hill, a ground storage tank should be constructed with a volume of 180,000 gal. In the areas with hotels (i.e., Isley and Puerto Rico), a storage tank of 630,000 gal should be constructed. Two diesel fire pumps rated at 2,000 gpm each should be used at the tanks in Puerto Rico and Isley. Two 1,000-gpm diesel fire pumps should be used at the tanks in Capitol Hill and Kobler.

54. Care must be taken to prevent cross connection of the systems through customer plumbing. Monitoring will be necessary once the system is installed to eliminate cross connections. Since the old distribution system would be used infrequently, air valves should be installed. Joint leaks may worsen in the old system if the system is left dry for periods of time.

55. The total cost of a ground storage tank fire system, including pumps and storage tanks, is estimated at $1.3 million. The total estimated cost for a dual system, based on the installation of ground storage tanks rather than the repair of existing system leaks, is $13.3 million.

Summary

56. Four distribution alternatives were evaluated for the Saipan water system. Either existing or different operations can be used with the existing network. Using existing operational practices requires labor-intensive valve manipulation. Connecting subsystems and reducing the number of pressure zones on the island offers a simpler operating scheme. Two alternatives, including complete replacement of the distribution network and a dual water system, will also offer operating simplicity. A dual system will preserve the high quality water from the upper level aquifers for drinking water purposes and provide adequate fire protection using the existing system and basal water supplies.

PART IV: CONCLUSIONS

57. A summary of advantages for each of the four distribution alternatives is presented in Table 12 with regard to four rating factors. For the combinations of source and distribution alternatives where sources are adequate to meet future demands, the letter "S" is given. Water quality is improved by the source alternatives involving abandonment of poor quality wells and addition of new wells. The alternatives demonstrating water quality improvements are noted by the letter "Q." Distribution alternatives that offer a simpler operational scheme than currently practiced are marked by the letter "O." An "X" denotes an infeasible solution. Three combinations of source and distribution alternatives offer the advantages of source adequacy, water quality improvement, and operational simplicity. These include (a) using the existing system with different operation, abandoning poor quality wells, adding new sources, leak repair (D2/A6); (b) complete replacement of system, abandoning poor quality wells, and adding new sources (D3/A6); and (c) dual water system, leak repair, or use of ground storage tanks (D4/A4). Appendix F gives a summary of nomenclature for each alternative. Simplifying system operation by reducing the number of separate systems while abandoning poor quality wells and adding new ones is more attractive than continuing to use poor quality water and the current inefficient operational practices. The choice between these three alternatives will depend on a detailed cost analysis and preference of the people of Saipan. Order of magnitude costs for each of the distribution/source alternatives are summarized in Table 13. The uncertainty of leak repair costs for the existing system is reflected in the costs expressed as ranges (i.e. $2-$12 million).

58. A leak detection survey is strongly recommended to locate leaks and to determine the magnitude of the effort required to repair the leaks. The distribution alternative of using the existing system with a different operational scheme (D2) and the source alternative of adding new sources and abandoning poor quality wells along with leak repair (A6) is the most economical combination of distribution/source alternatives that fully meets the island's need for adequate quantity of good quality water and a system that will run itself. However, the concept of a dual system is attractive. If the groundwater aquifers selected to provide additional source capacity in Alternative A6 prove to produce poor quality waters or to produce less than the

Table 12

Summary of Distribution Changes

Distribution Alternative	Source Alternatives A1	A2	A3	A4	A5	A6
D1 - Existing system with existing operation	X	S	S	S	X	S Q
D2 - Existing system with different operation	X	S O	O	S O	X	S O Q
D3 - Complete replacement of system	X	S O	NA	NA	X	S O Q
D4 - Dual water system	X	NA	NA	S O Q	X	NA

KEY:
S - source adequate
Q - quality improvement
O - operational simplicity
X - infeasible
NA - not applicable

A1 - existing sources, no leak repair
A2 - existing sources, leak repair
A3 - adding new sources, no leak repair
A4 - adding new sources, leak repair
A5 - adding new sources, abandon poor quality wells, no leak repair
A6 - adding new sources, abandon poor quality wells, leak repair

Table 13

Cost Summary

Distribution Alternative	Estimated Cost for Indicated Source Alternatives, $Million					
	A1	A2	A3	A4	A5	A6
D1	X	2.5-12.5	5.5	3.5-13.5	X	5.5-15.5
D2	X	3.3-13.3	6.3	4.3-14.3	X	6.3-16.3
D3	X	17-27	NA	NA	X	19.5-29.5
D4	X	NA	NA	14-24	X	NA

KEY: X - Infeasible
NA - Not applicable

D1 - existing system with existing operation
D2 - existing system with different operation
D3 - complete replacement of system
D4 - dual water system

A1 - existing sources, no leak repair
A2 - existing sources, leak repair
A3 - adding new sources, no leak repair
A4 - adding new sources, leak repair
A5 - adding new sources, abandon poor quality wells, no leak repair
A6 - adding new sources, abandon poor quality wells, leak repair

predicted rates, the D2/A6 combination may not prove adequate. Therefore, a dual system (Alternative D4/A4) should be considered since it can meet the water needs and provide consumers with water that meets the standards recommended by the Safe Drinking Water Act.

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APPENDIX A: SAIPAN WATER SUPPLY STUDY MODEL DEVELOPMENT AND CALIBRATION

Introduction

1. The Saipan water supply and distribution system has been studied for several years. GK2, Inc./CE Maguire, Inc. (1982)* concluded that "the deteriorated condition of the water pipe installed some 30 to 40 years ago results in an abnormally high leakage rate." The report goes on to say that "the line leakage, coupled with the water hour rationing system, results in contaminated water being supplied to the Saipan consumer" and that "the very high water line friction losses and leakage results in nearly one-half of the energy supplied to the pumps being wasted." Based on these conclusions, additional raw water sources need to be explored and existing pipelines and appurtenances need to be repaired or replaced. The water system also has several other problems which need to be resolved (e.g. contamination, rationing requirements, high energy costs, inadequate inventory of maintenance materials).

2. The US Army Engineer Waterways Experiment Station (WES) was requested by the US Army Engineer Division, Pacific Ocean (POD), to provide assistance in the Northern Mariana Islands Comprehensive Study using the Methodology for Areawide Planning Studies (MAPS) computer program (Office, Chief of Engineers 1980). MAPS is a comprehensive set of computer models which can be used to simulate water resource alternatives and to develop planning level design and cost estimates. The distribution analysis portion of MAPS, called WADISO, will be used to model the Saipan transmission network for the purpose of evaluating several proposed alternatives/improvements to the system based on technical and economic considerations. Detailed information about the WADISO program is found in Gessler and Walski (1985).

3. The first phase of work requested by the POD involved (a) collection of pressure and flow data on Saipan, (b) calibration of the model, and (c) transfer of the model to the POD. This report will serve to document these completed tasks.

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* See References at the end of the main text.

Model of Existing Distribution System

4. The WADISO computer program was used to predict the flows and pressures within the Saipan distribution system. A mathematical model of the pipe network was constructed and then calibrated to fit actual pressure data recorded during field tests. The model was used to evaluate several alternatives to the Saipan water system and to test the GK2, Inc./CE Maguire, Inc. recommendations (GK2, Inc./CE Maguire, Inc. 1982).

Model construction

5. The network model for the Saipan system was actually several models, one for each pressure service area. These service areas can be interconnected, but the Saipan Water Department operates these as nine separate systems by closing valves between service areas. Therefore, for calibration the systems were modeled separately. The development of each model began with the identification of links (pipe segments, pumps, pressure-reducing valves) and nodes (pipe junctions, use points, tanks). Nodes for each model were identified by junctions of two or more mains, changes in pipe diameter (8-in. main connected to a 6-in. main, etc.), and ends of mains. The pipes between these nodes were then defined as links in the model. Each pipe link was described by its length, diameter, Hazen-Williams C-factor, and the node numbers at the ends of the pipe. The lengths and diameters of the mains were derived from the available mapping of the system.

6. The node numbers were designated on a 1 in. = 2,100 ft map of the system. The map of the Saipan water system showing data used for the computer model is included in this report as Appendix B. The node identifying data consisted of ground elevations and outflow and inflow values. Most of the elevations were estimated from blueline drawings of the distribution system which had 10-ft contour intervals. Current water use data was obtained from GK2, Inc./CE Maguire, Inc. (1982) for each service area. Water use was equally distributed to all nodes within the service area. Pump characteristic curves (head vs. discharge) were gathered from other reports (GK2, Inc./CE Maguire, Inc. 1982; Nance 1983) and later verified in the field.

7. WES then entered the data into the WADISO computer program. An example of the model input is given in Table A1. The coded data were then stored as data files on the Control Data Corporation (CDC) computer system.

Table A1

Example of Model Input

```
1
JOB TASA SUBSYSTEM
PIPE 590 592 590 6 960
PIPE 592 596 592 12 1660
PIPE 596 598 596 6 600
PIPE 598 598 610 6 4830
PIPE 600 600 598 6 100
PIPE 610 610 612 6 490
PIPE 612 612 614 6 620
PIPE 614 614 616 6 2240
PIPE 615 612 616 6 1950
PIPE 616 616 618 6 500
PIPE 618 610 618 6 1670
PIPE 619 618 620 6 5500
PIPE 622 620 622 6 1140
PIPE 624 620 624 8 450
PIPE 626 620 626 8 1120
PIPE 627 628 626 8 150
PIPE 628 624 628 8 1050
PIPE 632 624 632 6 2525
PIPE 499 499 594 8 2880
PIPE 597 597 499 6 100
PIPE 591 591 597 6 100
PIPE 594 594 596 6 280
ELEV 594 178
```

Pipe Data

```
ELEV 595 1
ELEV 499 197
ELEV 593 1
ELEV 597 131
ELEV 591 131
ELEV 592 25
ELEV 590 25
ELEV 600 173
ELEV 596 160
ELEV 598 35
ELEV 610 22
ELEV 612 10
ELEV 614 5
ELEV 616 22
ELEV 618 42
ELEV 620 25
ELEV 622 20
ELEV 624 22
ELEV 626 72
ELEV 628 75
ELEV 632 55
```

Node Elevations

```
COEF 105
```

C-Factor

```
OUTP 592 11
```

Water Use

Table A1 (Concluded)

```
OUTP 628 180   |
OUTP 590 11    |
OUTP 610 11    |
OUTP 612 11    |
OUTP 614 11    |
OUTP 616 11    |  Water
OUTP 618 11    |  Use
OUTP 620 11    |
OUTP 622 11    |
OUTP 624 11    |
OUTP 626 11    |
OUTP 632 11    |
TANK 600 10.25 |
TANK 595 0     |  Tank
               |  Water
TANK 593 0     |  Level
PUMP 595 595 597 | Pump Location
70 230  | Pump Curve
E  | End of Pump Data
PUMP 593 593 591 |
70 230           |  Pump Data
E                |
END  | End of Input
0C
9
 EOI ENCOUNTERED.
```

These data files were then used as input to the WADISO distribution computer model for the calibration runs.

Model calibration

8. The model's ability to predict actual measured pressure data was tested in the model calibration step. The computer simulated heads were compared with the actual recorded heads in a series of runs using different C-factors and outflow values. A discussion of the calibration approach used for this model is found in Walski (1984).

9. This calibration was based on pressure and tank water level data recorded during a series of field tests conducted 18-24 August 1984. Table A2 contains data collected during the hydrant static and flow tests. For many hydrants only a static pressure reading was taken, while for others an adjacent hydrant was opened, and a flow test was conducted as described in American Water Works Association Manual No. M17 "Installation, Field Testing and Maintenance of Fire Hydrants."

10. The data contained in each column of Table A2 are described in greater detail below.

11. Column 1. The service area is the area served by the hydrant at which the static pressure gage was located. The nearest hydrant to this hydrant is the one that was allowed to flow.

12. Column 2. The hydrants to be tested were selected partly based on their proximity to node points in the water distribution network model being developed by WES. The node number at which the hydrant is located is given in column 2.

13. Column 3. The date on which the test was conducted is given in column 3. The number 20 indicates that it was conducted 20 August 1984.

14. Column 4. The elevation of the hydrant above mean sea level (msl) was obtained from blueline drawings of the distribution system with 10-ft contour intervals. The data should only be considered accurate to ±5 ft.

15. Column 5. The pressure (in pounds per square inch) recorded at the hydrant under normal flows is given in column 5.

16. Column 6. The elevation (in feet) of the hydraulic grade line (HGL) under normal flows is given in column 6. It is calculated using

$$HGL = E + 2.31\ P \qquad \text{(A1)}$$

Table A2

Results of Hydrant Tests

(1) Service Area	(2) Node No. in Model	(3) Date of Test Aug 84	(4) Elevation of Hydrant ft	Static (5) Pressure psi	Static (6) HGL ft	Residual (7) Pressure psi	Residual (8) HGL ft	(9) Test Flow gpm
San Antonio	176	20	5	18	46			
San Antonio	180	20	5	19	49			
San Antonio	194	20	5	18	46			
San Antonio	192	20	5	12.4	34	5.7	18	330
San Antonio	186	20	5	18.5	48			
Chalan Kanoa	260	20	5	12.5	34	7	21	410
Chalan Kanoa	266	20	5	12.5	34			
Chalan Kanoa	312	20	5	12.5	34	5.1	17	290
Chalan Kanoa	288	20	5	11	30			
Chalan Kanoa	304	20	5	11.5	31			
Chalan Kanoa	243	20	5	13.2	35			
Chalan Kanoa	210	20	5	14.6	39			
Gualo Rai	362	20	153	68.5	310			
Gualo Rai	358	20	108	87	308			
Calhoun	474	21	370	42.5	468			
Calhoun	465	21	40	120	316			
Calhoun	462	21	40	114	302			
Calhoun	458	21	75	78	254			
Calhoun	456	21	30	105	272			
Calhoun	398	21	78	75	251			
Tasa	614	21	16	57	147			
Tasa	618	21	48	42	145			
Tasa	620	21	25	49	138	27	87	180
Tasa	626	21	52	34	130			
Tasa	628	21	82	23	135			
Tasa	624	21	22	47	130			
Tasa	620	21	25	52	145			
Tasa	592	21	16	68	172			

(Continued)

Table A2 (Concluded)

(1) Service Area	(2) Node No. in Model	(3) Date of Test Aug 84	(4) Elevation of Hydrant ft	Static (5) Pressure psi	Static (6) HGL ft	Residual (7) Pressure psi	Residual (8) HGL ft	(9) Test Flow gpm
San Vicente	20	22	275	34	353			
San Vicente	12	22	265	34	343	8	283	600
San Vicente	16	22	210	43.5	310			
San Vicente	138	22	160	36	243			
San Vicente	24	22	282	30	351			
San Vicente	6	22	275	25	333			
San Vicente	154	22	131	53	253			
San Vicente	158	22	131	56	260			
Puerto Rico	438	22	5	67	159			
Puerto Rico	422	22	5	65	155			
Puerto Rico	414	22	5	65	155			
Puerto Rico	424	22	5	68	161			
Puerto Rico	434	22	5	68.5	163			
Puerto Rico	460	22	5	65	155			
Puerto Rico	412	22	5	68	164			
Puerto Rico	376	22	8	60	143	50	120	890
Puerto Rico	372	22	8	67	159	50	120	855
Puerto Rico	368	22	5	67	159			
Puerto Rico	354	22	16	57	147			
Puerto Rico	356	22	58	40	150			
Puerto Rico	315	22	5	66	157			
Capitol Hill	520	23	753	45	856			
Capitol Hill	550	23	675	62	818			
Capitol Hill	558	23	664	66	816			
Capitol Hill	560	23	615	85	810	32	689	480
Capitol Hill	562	23	580	97.5	804			
Koblerville	170	23	66	35	147			
Koblerville	172	23	59	36	142			

where

HGL = height of hydraulic grade line, ft

E = elevation of hydrant, ft

P = pressure at hydrant, psi

17. Columns 7 and 8. Columns 7 and 8 contain the same information as given in columns 5 and 6, respectively, except that the entries are for the case in which the adjacent hydrant is flowing.

18. Column 9. Column 9 contains the flow from the adjacent hydrant rounded usually to the nearest 30 gpm.

19. The pressure data were measured using a Bourdon type pressure gage which was generally accurate to ±1 psi. Values over 100 psi were read with a gage that was accurate to ±3 psi. The hydrant flows were measured with a Pollard hydrant flow gage. The gage was able to measure flows up to 1,300 gpm. Locations of pressure readings are shown on distribution schematics of each service area in Figures A1-A9. The static pressures in pounds per square inch are recorded along with the hydraulic head in feet. The base maps were obtained from GK2, Inc./CE Maguire, Inc. (1982).

20. In addition to pressure data, the system's tank levels and pump operations were recorded for the testing period in each service area. Water levels in the tanks were read directly at the tank and are recorded in Table A3. Each pump contributing inflow to a service area was left on during the testing period. When flow meters were available and operating at well sites, the flow was recorded. At well sites where a pressure gage could be attached at the discharge end of the pump, pressure was recorded for zero discharge (value at pump shut) and operating discharge (value at pump open). The recorded pressure was converted to pump head and is summarized in Table A4. These data were used to verify pump head curves.

Results of Calibration

21. Calibration of the model was achieved by running the program several times while adjusting C-factors and water use rates until the model accurately predicted pressures observed in the field. (Walski (1984) discusses the calibration of water distribution system models.) The C-factors used to achieve calibration ranged from 55 to 105. Water use in each service area ranged from 0.02 MGD to 177 MGD. The results of the calibration runs are

summarized in Table A5. The predicted values for the HGL under normal flow conditions are recorded in column 4 of Table A5. The predicted values for the HGL under fire flow conditions are presented in column 6. The results of the calibration indicate that the models can adequately predict pressure and flow in each service area of the Saipan water distribution system. A detailed computer printout for an example run is presented in Table A6. Negative OUTPUTS are inflows to the system at tanks and wells. RESERVOIR denotes a tank and SUPPLY refers to a well. The pump data are given in the PIPE DATA section of the table. For example, at pump link 593 the head is 188.8 ft, discharge is 87 gpm, and the water power is 4 hp. An "*" indicates that a global C-factor is used.

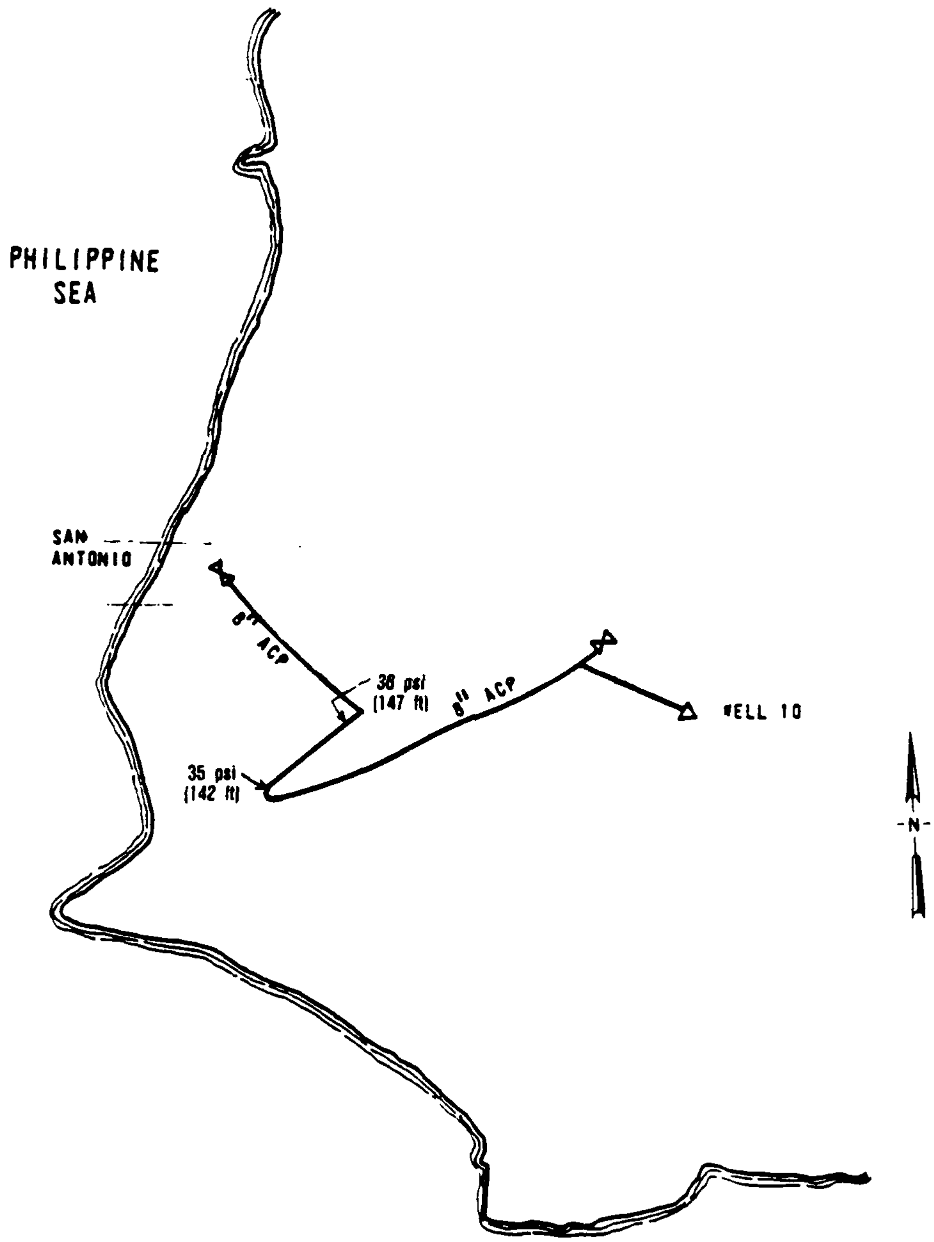


Figure A1. Kobler field system: distribution schematic and static pressures and heads

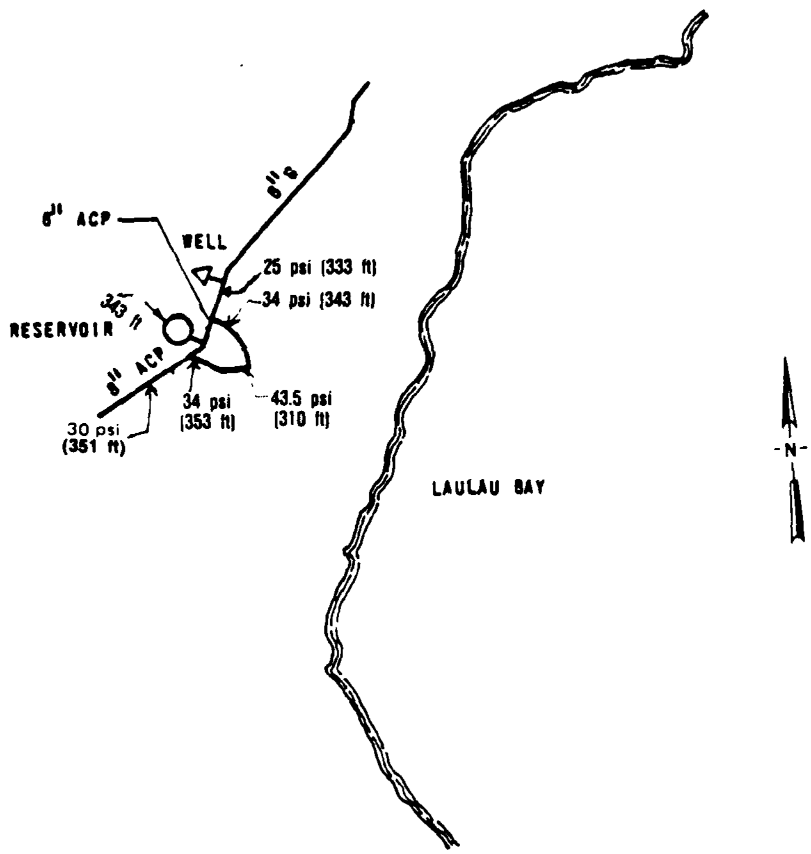


Figure A2. San Vicente system: distribution schematic and static pressures and heads

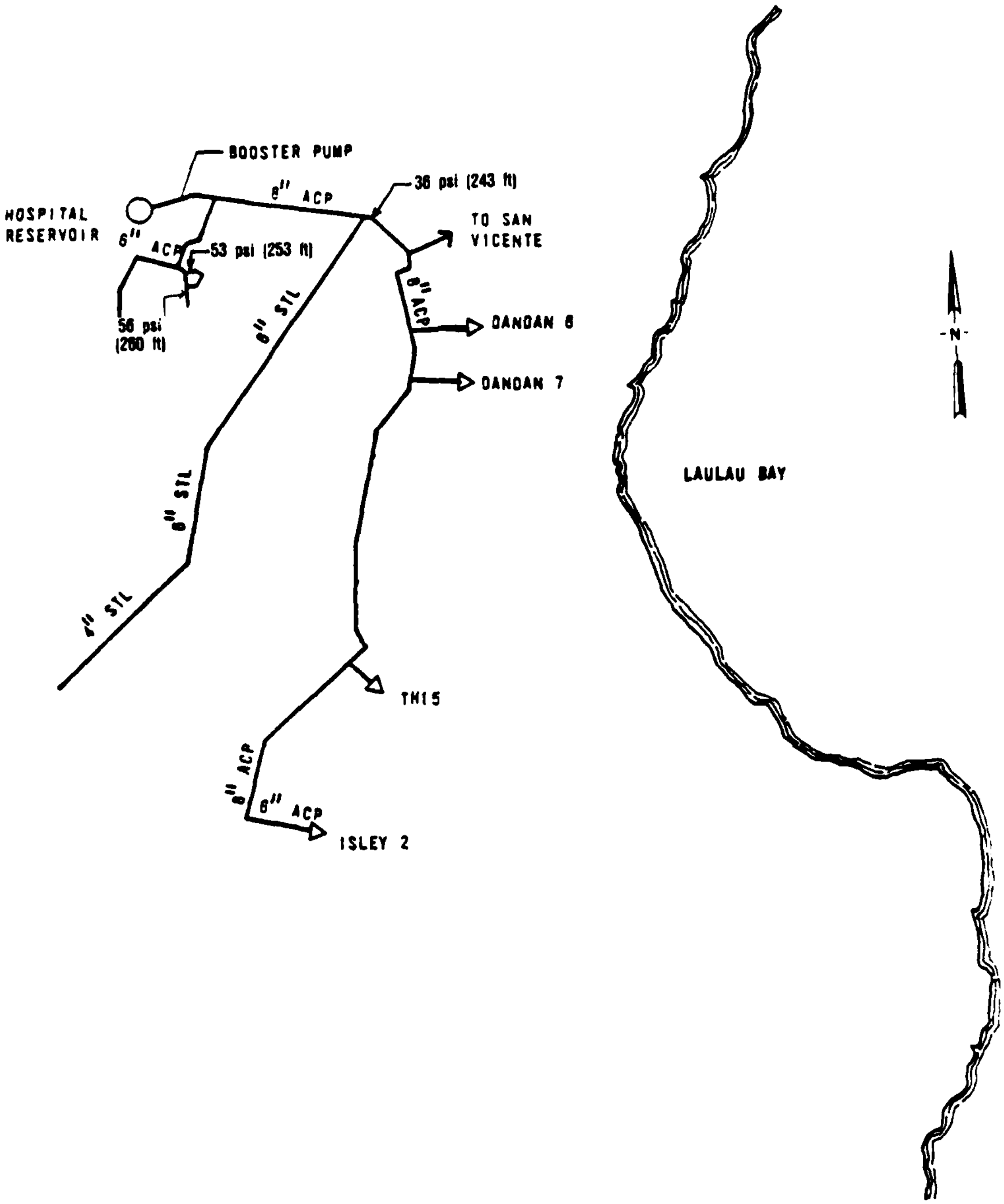


Figure A3. Isley/Dandan system: distribution schematic and static pressures and heads

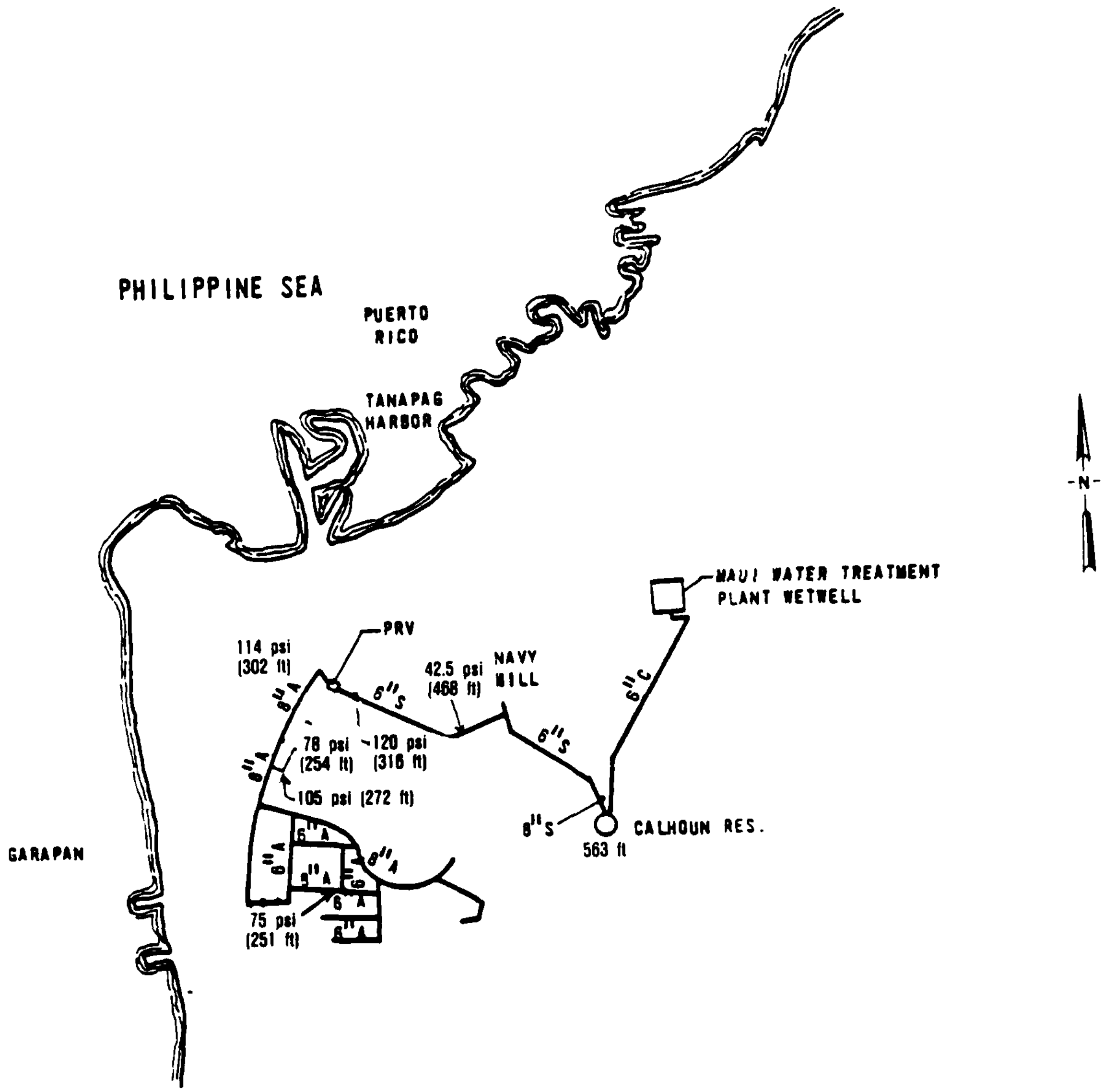


Figure A4. Calhoun system: distribution schematic and static pressures and heads

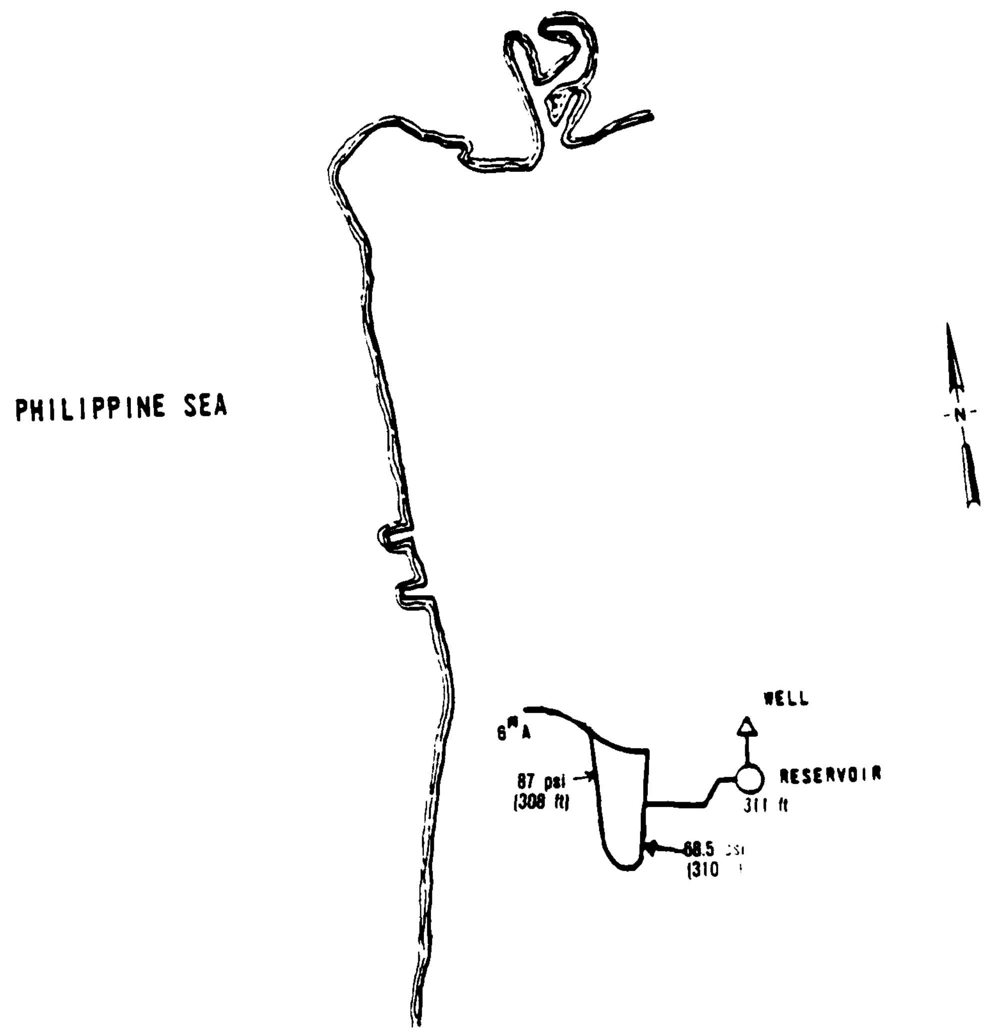


Figure A5. Gualo Rai system: distribution schematic and static pressures and heads

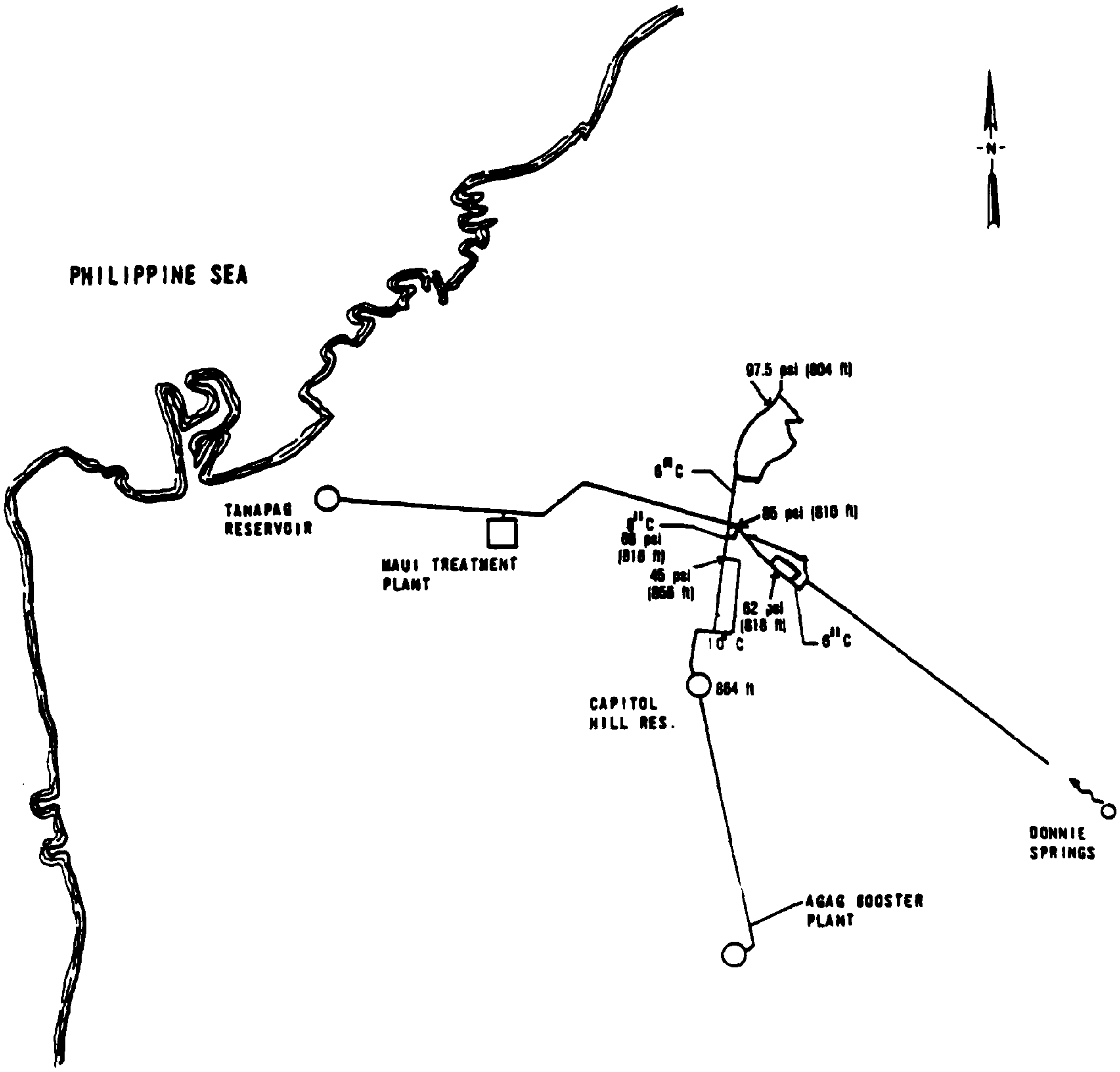


Figure A6. Capitol Hill and Donni Springs system: distribution schematic and static pressures and heads

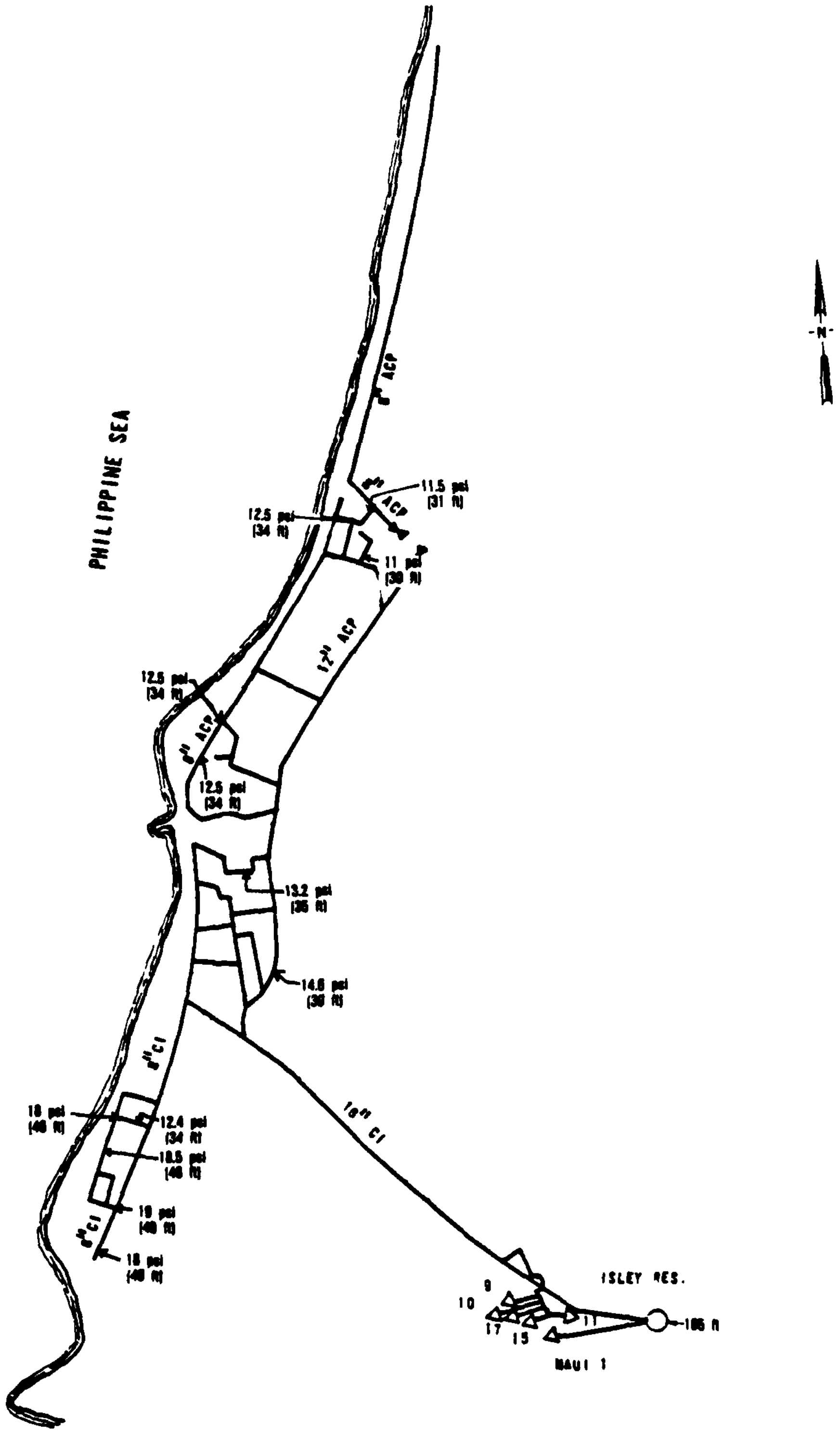


Figure A7. Chalan Kanoa/San Antonio system: distribution and schematic and static pressures and heads

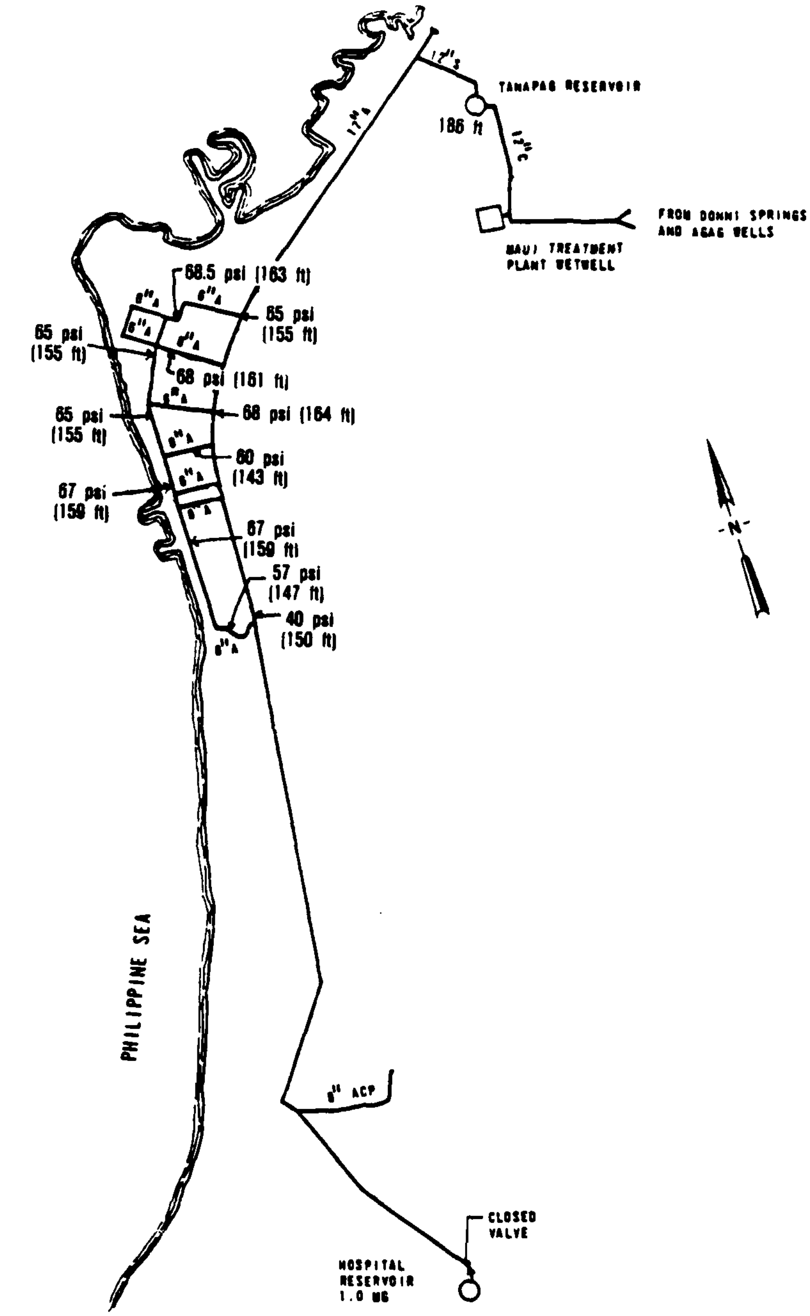


Figure A8. Puerto Rico system: distribution schematic and static pressures and heads

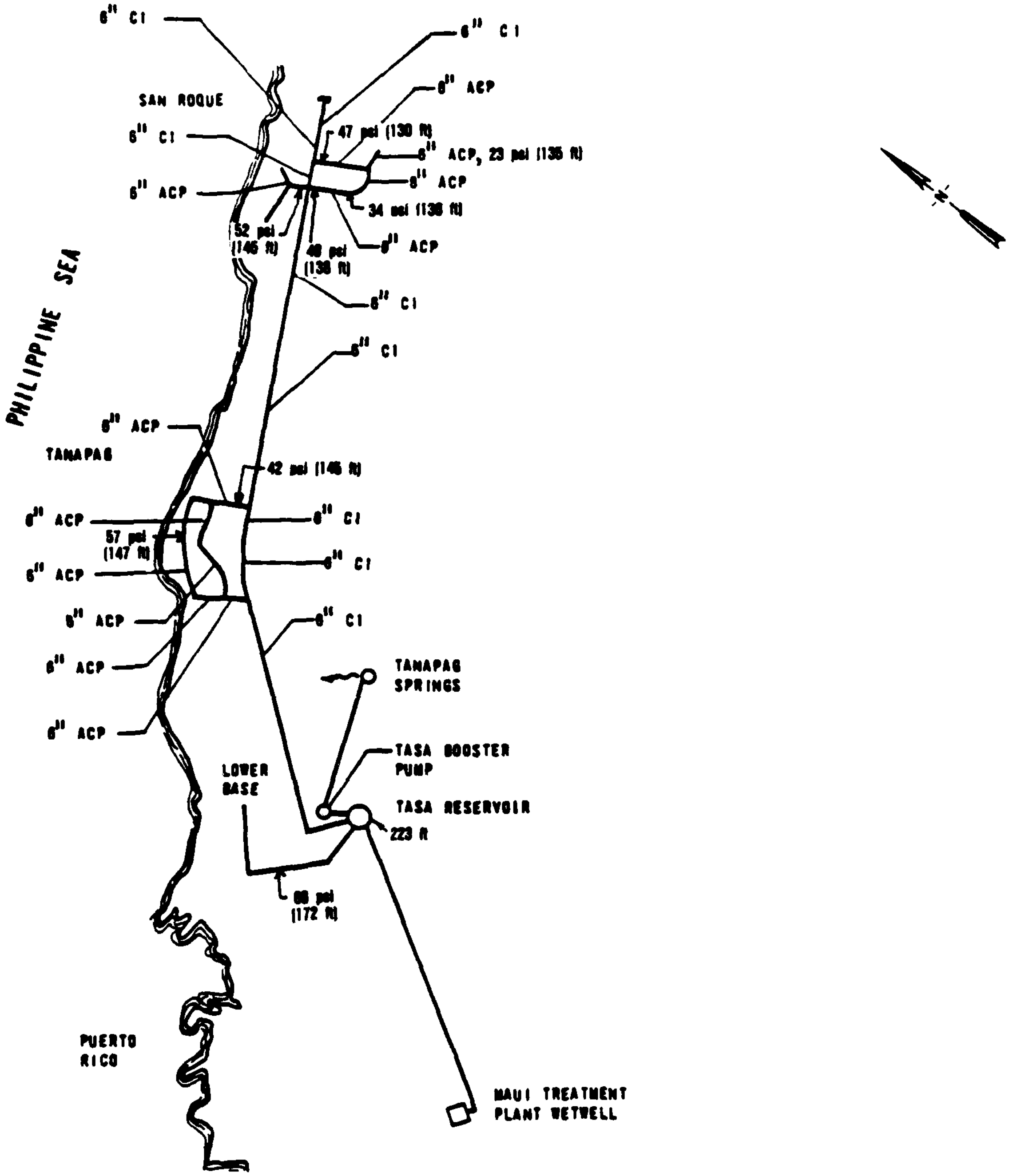


Figure A9. Tasa system: distribution schematic and static pressures and heads

Table A3
Water Levels in Tanks

Location	Date Aug 84	Node No. in Model	Beginning Elevation* ft	Ending Elevation* ft	Node Elevation ft	HGL ft
Gualo Rai	20	364	11.3	11.1	300	311
Isley (Chalan Kanoa/ San Antonio)	20	72	1.5	2.0	184	186
Calhoun	21	492	13.3	13.3	550	563
Tasa	21	600	10.25	10.25	213	223
Puerto Rico	22	578	35.6	39.0**	150	186
San Vicente	22	22	22.7	22.7	320	343
Capitol Hill	23	526	5.2	3.5	860	864

* The beginning elevation refers to the water level in the tank at the start of the testing period for the area served by that tank. When pressure readings and fire flow tests were completed for a service area, the water level was read and recorded as ending elevation.

** Reservoir level read at 7:05 pm but testing was completed at 2:00 p.m.

Table A4
Heads at Pumps

Service Area	Well No.	Date Aug 84	Pump Head, ft Operating Flow	Pump Head, ft Zero Discharge	Node No. in Model
Gualo Rai	151	20	20	237	365
Isley	104	20	38	368	62
Isley	109	20	16	396	68
Isley	103	20	14	460	71
Isley	11	20	106	-	118
Isley	111	20	28	200	114
Isley	113	20	120	322	101
Capitol Hill	70	22	18	258	
Kagman	76	22	150	306	657
San Vicente	106	22	104	455	44
San Vicente	107	22	113	363	48
San Vicente	102	22	104	575	52
San Vicente	108	22	87	334	56
San Vicente	7	22	85	402	38
Tasa	148	22	124	175	
Puerto Rico	162	22	58	448	576
Puerto Rico	164	22	46	253	582

Table A5
Results of Model Calibration

(1) Service Area	(2) Node Number in Model	Hydraulic Grade Line* at Normal Flow, ft (3) Field	(4) Predicted	Hydraulic Grade Line at Fire Flow, ft (5) Field	(6) Predicted	(7) Fire Flow gpm
Tasa	618	145	148			
Tasa	620	138	138	87	82	180
Tasa	624	130	138			
Tasa	614	147	138			
Tasa	626	130	149			
Tasa	628	135	138			
Tasa	592	172	182			
San Vicente	20	353	340			
San Vicente	16	310	340			
San Vicente	138	243	242			
San Vicente	12	343	340	283	286	600
San Vicente	18	336	340			
San Vicente	24	351	340			
San Vicente	6	333	340			
Gualo Rai	362	321	311			
Gualo Rai	358	308	311			
San Antonio	176	46	36			
San Antonio	180	49	36			
San Antonio	194	46	36			
San Antonio	192	34	36	18	12	330
San Antonio	186	48	33			
Chalan Kanoa	260	34	38	21	18	410
Chalan Kanoa	266	34	38			
Chalan Kanoa	312	34	38	17	30	290
Chalan Kanoa	288	30	36			
Chalan Kanoa	304	31	34			

(Continued)

* Hydraulic grade line (ft) = (static pressure (psi) × $\frac{2.3\ \text{ft}}{\text{psi}}$) + (ground elevation (ft)).

Table A5 (Concluded)

Service Area	Node Number in Model	Hydraulic Grade Line* at Normal Flow, ft		Hydraulic Grade Line at Fire Flow, ft		Fire Flow gpm
		Field	Predicted	Field	Predicted	
Chalan Kanoa	243	35	33			
Chalan Kanoa	210	39	45			
Puerto Rico	438	159	153			
Puerto Rico	422	155	154			
Puerto Rico	414	155	154			
Puerto Rico	424	161	154			
Puerto Rico	434	163	153			
Puerto Rico	460	155	159			
Puerto Rico	412	164	155			
Puerto Rico	376	143	153	120	114	890
Puerto Rico	372	159	154	120	121	855
Puerto Rico	368	159	154			
Puerto Rico	354	147	154			
Puerto Rico	356	150	154			
Puerto Rico	315	157	154			
Capitol Hill	520	856	842			
Capitol Hill	550	818	837			
Capitol Hill	558	816	813			
Capitol Hill	560	810	813	689	689	480
Capitol Hill	562	804	810			
Calhoun	474	468	459			
Calhoun	465	316	314			
Calhoun	462	302	303			
Calhoun	458	254	260			
Calhoun	456	272	261			
Calhoun	398	251	250			
Koblerville	170	147	144			
Koblerville	172	142	144			

Table A6
Example of Model Output

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: TASA SUBSYSTEM

NODE DATA PAGE 1

NODE NO.	ELEV. FT.	OUTPUT GPM	E.G.L. FT.	PR.HEAD FT.	PRESSURE PSI	
499	197.0		189.3	-7.7	-3.3	
590	25.0	11.	185.0	160.0	69.3	
591	131.0		189.8	58.8	25.5	
592	25.0	11.	185.0	160.0	69.3	
593	1.0	-87.	1.0			RESERVOIR
594	178.0		186.2	8.2	3.6	
595	1.0	-87.	1.0			RESERVOIR
596	160.0		185.0	25.0	10.8	
597	131.0		189.7	58.7	25.4	
598	35.0		183.0	148.0	64.1	
600	173.0	-138.	183.2	10.2	4.4	SUPPLY
610	22.0	11.	128.8	106.8	46.3	
612	10.0	11.	127.2	117.2	50.8	
614	5.0	11.	126.8	121.8	52.8	
616	22.0	11.	125.6	103.6	44.9	

Table A6 (Continued)

618	42.0	11.	124.6	82.6	35.8
620	25.0	11.	82.8	57.8	25.1
622	20.0	11.	82.8	62.8	27.2
624	22.0	11.	82.6	60.6	26.3
626	72.0	11.	82.4	10.4	4.5
628	75.0	180.	82.3	7.3	3.2
632	55.0	11.	82.6	27.6	11.9

JOB: TASA SUBSYSTEM

PIPE DATA AGE 2

PIPE NO.	NODES FROM	TO	DIAM. IN.	LENGTH FT.	COEF	FLOW GPM	VEL. FT/SEC	HEAD LOSS
499	499	594	8.0	2880.0	105.*	174.	1.1	3.1
590	592	590	6.0	960.0	105.*	11.	.1	.0
591	591	597	6.0	100.0	105.*	87.	1.0	.1
592	596	592	12.0	1660.0	105.*	22.	.1	.0
593	593	591	PUMP HEAD	188.8 FT		87.	POWER	4. HP
594	594	596	6.0	280.0	105.*	174.	2.0	1.2
595	595	597	PUMP HEAD	188.7 FT		87.	POWER	4. HP

Table A6 (Concluded)

I	596	596	598	6.0	600.0	105.*	152.	1.7	2.0	I
I	597	597	499	6.0	100.0	105.*	174.	2.0	.4	I
I	598	598	610	6.0	4830.0	105.*	290.	3.3	54.1	I
I	600	600	598	6.0	100.0	105.*	138.	1.6	.3	I
I	610	610	612	6.0	490.0	105.*	149.	1.7	1.6	I
I	612	612	614	6.0	620.0	105.*	66.	.8	.5	I
I	614	614	616	6.0	2240.0	105.*	55.	.6	1.2	I
I	615	612	616	6.0	1950.0	105.*	71.	.8	1.6	I
I	616	616	618	6.0	500.0	105.*	116.	1.3	1.0	I
I	618	610	618	6.0	1670.0	105.*	130.	1.5	4.2	I
I	619	618	620	6.0	5500.0	105.*	235.	2.7	41.8	I
I	622	620	622	6.0	1140.0	105.*	11.	.1	.0	I
I	624	620	624	8.0	450.0	105.*	109.	.7	.2	I
I	626	620	626	8.0	1120.0	105.*	104.	.7	.5	I
I	627	626	628	8.0	150.0	105.*	93.	.6	.1	I
I	628	624	628	8.0	1050.0	105.*	87.	.6	.3	I
I	632	624	632	6.0	2525.0	105.*	11.	.1	.1	I

I---I

SELECT PROGRAM OPTION :

TO BALANCE : ENTER 0 OR 0C PRESS RETURN

APPENDIX B: WATER DISTRIBUTION SYSTEM MAP

See map enclosed in the pocket in the back cover of this report.

APPENDIX C: ANALYSIS OF PREVIOUSLY PROPOSED CAPITAL IMPROVEMENT PROGRAM

1. A $10 million (1982 dollars) capital improvement program, including main replacement and leak repair, was proposed by CE Maguire, Inc., in their 1982 report, "Saipan Water Systems Study." The US Army Engineer Waterways Experiment Station (WES) was requested by the US Army Engineer Division, Pacific Ocean, to analyze these proposed improvements using the WES-developed computer model of Saipan's water distribution system. A brief description of the suggested improvements and results of the analyses of these changes are given, first considering that only the mains are replaced and then considering that the mains are replaced and service laterals are repaired.

2. The capital improvement plan was developed on the basis that the water system would continue to operate as separate subsystems. The following benefits of the recommended improvements were identified:

- a. The residences of Saipan will be provided with a 24-hr water supply.
- b. The water transmission and distribution lines will always be full, thereby precluding contamination of the water supply through infiltration of contaminated groundwater into the empty pipelines.
- c. Pumping of the basal lens will be decreased, thereby lowering the chloride content of the water and consequently bringing the quality of the water closer to the requirements of the Safe Drinking Water Act.
- d. Power costs for water pumpage will be reduced.

Specific tasks in the program include the repair or replacement of service meters, replacement of deteriorated or inadequately sized pipelines, repair of service laterals, new storage facilities, and repair or replacement of some pumps. A summary of the recommended improvements is given in Table C1.

3. The WES computer model simulated the replacement of pipelines in Alternative B1 and the replacement of pipeline and service lateral repair in Alternative B2. Main replacement was modeled by changing the C-factor, a measurement of the roughness of the pipe, to a value characteristic of new pipe (i.e., 130). A higher C-factor results in lower friction losses in the pipe which in turn results in higher pressures. Replacement of deteriorated pipelines will result in reduced leakage, so the estimated water use (consumption plus leakage) was decreased based on the percentage of lines repaired in each

Table C1

Summary of Proposed Improvements* to the Saipan Water System

Village	Pipeline Replacement, ft	Number of Service Laterals Repaired	Number of Pumps to be Replaced	Number of Storage Tanks to be Replaced
Isley	25,800	500	0	0
San Vicente	14,400	100	0	0
Gualo Rai	0	40	0	0
Calhoun	13,400	220	1	1
Puerto Rico	700	220	0	1**
Capitol Hill	29,200	0	1	1
Tasa	24,000	120	0	0

* CE Maguire, Inc., recommendations, Saipan Water Systems Study (1982).
** 1.0-million-gallon reservoir to balance flow into and out of the Maui IV distribution box area.

service area. For example, half of the water loss in an area was attributed to leaks in mains and half to leaks in service laterals. In the area of Isley where the water use was estimated as 260 gpcd (100 gpcd used, 160 gpcd leakage), half of 160 (80 gpcd) was multiplied by one minus the ratio of the length of pipeline repaired to the total pipeline length. In Isley, 25,800 ft of the total 84,715 ft was to be replaced. Therefore,

$$\text{New Water Use} = 0.5(160)\left(1 - \frac{25,800}{84,715}\right) + 0.5(160) + 100 = 236 \text{ gpcd} \qquad \text{(C1)}$$

A value of 100 gpcd is added to the equation as the amount of water expected to be consumed (i.e., not lost to leakage).

4. In Alternative B2, leakage is reduced further by repairing leaking service laterals. Water use is decreased by the ratio of the number of service laterals repaired to the total number of service laterals. For example, 500 of the total 1,280 service laterals in the Isley area are to be repaired. Therefore, the water use was corrected by

$$\text{New Water Use} = 0.5(260)\left(1 - \frac{25,800}{84,715}\right) + 0.5(260)\left(1 - \frac{500}{1,280}\right) + 100 = 204 \text{ gpcd} \quad \text{(C2)}$$

By performing similar calculations for each of the areas with proposed changes, C-factors and water use rates were modified in the distribution system model to accurately represent the systems described by Alternatives B1 and B2. In each alternative the following scenarios were simulated:

- a. Normal day use - year 2000
- b. Normal day use - year 2040
- c. Peak hour use - year 2000
- d. Peak hour use - year 2040
- e. Hotel fire - year 2000
- f. Hotel fire - year 2040
- g. Population center fire - year 2000
- h. Population center fire - year 2040

Peak hour use was estimated as 2.5 times normal day use. Discharge from a fire hydrant required to fight a hotel fire was taken as 2,000 gpm and to fight a residential fire was taken as 500 gpm. During fire flow conditions, water use rates were taken as 1.5 times normal day use.

5. Main replacement alone (Alternative B1) is not sufficient to reduce the amount of leakage in the system so that the system is adequate for future needs. Table C2 gives the water demand (i.e., the normal day water use including water lost to leaks) in 2000 and 2040 for each village with proposed changes under the CE Maguire, Inc., program. Also listed is the difference between water source availability and demand. The capacity of the existing wells was taken at 80 percent of the rated capacity to account for downtime, repairs, and inefficient pumps. A water shortage is predicted for every village in the year 2040 and in every village except Capitol Hill and Gualo Rai in the year 2000. A total deficit of 2,822 gpm and 3,614 gpm is predicted for the years 2000 and 2040, respectively. The total potential yield, not presently used, was estimated by the US Geological Survey as 3,398 gpm (see Table 7 in main text). Assuming that this potential yield is available and can be used, the water needs can be met in 2000 but not in 2040 under Alternative B1. Of course, the adequacy of the sources will also be determined by the number of wells that have to be abandoned because of poor quality. This

is indicated by inadequate pressures for normal flow and fire fighting conditions.

6. The repair of leaking service laterals provides an additional reduction in leakage in Alternative B2. However, these proposed improvements only offer a temporary solution to the water system problems on Saipan. The water balance for Alternative B2 is given in Table C3 and shows that this alternative will also fail to meet water demands in 2000 and 2040. A deficit of 1,658 gpm is predicted for the year 2000 and 2,279 gpm for the year 2040. The yield provided by groundwater areas not presently used can meet the water demand in 2000 and 2040 but source adequacy will depend on the number of wells abandoned because of poor quality water and the quality of water from the new groundwater areas.

7. The CE Maguire, Inc., recommendations do not provide adequate pressures in all areas in future years under normal flow and fire fighting conditions. Only the Isley service area, with these improvements, has significantly improved pressures over the existing system. Results of the distribution modeling are presented in Appendix D. Although, the CE Maguire recommendations provide some immediate benefits, long-term benefits and adequacy of the system to meet future demands can only be provided by major changes to the distribution network and operational practices. Part III of this report discussed these alternatives.

Table C2

Source Analysis for Alternative B1

Village	Water Demand, gpm Year 2000	Water Demand, gpm Year 2040	Well Capacity - Demand, gpm Year 2000	Well Capacity - Demand, gpm Year 2040
Calhoun	734	903	-510	-679
Capitol Hill	448	598	+24	-126
Gualo Rai	64	107	+12	-31
Isley	1590	1655	-846	-911
Puerto Rico	2252	2466	-1,148	-1,362
San Vicente	532	638	-248	-354
Tasa	198	243	-106	-151
		Total Water Deficit	-2,822	-3,614
			(-4.06 MGD)	(-5.20 MGD)

Table C3

Source Analysis for Alternative B2

Village	Water Demand, gpm Year 2000	Water Demand, gpm Year 2040	Well Capacity - Demand, gpm Year 2000	Well Capacity - Demand, gpm Year 2040
Calhoun	292	360	-68	-136
Capitol Hill	448	598	+24	-126
Gualo Rai	58	97	+18	-21
Isley	1374	1430	-630	-686
Puerto Rico	1838	2012	-734	-908
San Vicente	446	535	-162	-251
Tasa	198	243	-106	-151
		Total Water Deficit	-1,658	-2,279
			(-2.39 MGD)	(-3.28 MGD)

APPENDIX D: ANALYSES OF DISTRIBUTION MODELING

1. The following is a discussion of computer modeling of the existing Saipan distribution system (Alternative A1/D1), the existing system with leak repair (Alternative A2/D1), and the existing system with the CE Maguire, Inc., recommendations (i.e., main replacement (Alternative B1) and main replacement plus service lateral repair (Alternative B2)). See Parts II and III of this report for more information about Alternatives A1 and A2 and Appendix C of this report for more information about Alternatives B1 and B2. This appendix evaluates distribution system pressures (independent of source adequacy) while Part II and Appendix C evaluate source adequacy for Alternatives A1, A2, B1, and B2. Both future demands and pressure requirements must be met for the system to be adequate.

2. The developed computer model described in Appendix A was used to simulate future conditions for each alternative. These conditions included:

a. Normal flow - year 2000.

b. Normal flow - year 2040.

c. Peak flow - year 2000.

d. Peak flow - year 2040.

e. Residential fire flow - year 2000.

f. Residential fire flow - year 2040.

g. Hotel fire flow - year 2000.

h. Hotel fire flow - year 2040.

Peak hour use was estimated as 2.5 times normal day use. Discharge from a fire hydrant to fight a hotel fire was assumed to be 2,000 gpm and to fight a residential fire was assumed to be 500 gpm. During fire flow conditions, water use rates were assumed to be 1.5 times normal day use. Each of the simulations was evaluated for the adequacy of the system to meet minimum recommended pressure requirements (i.e., 40 psi at a residence during normal flow conditions and 20 psi at a fire hydrant during fire flow conditions). Tables D1-D4 summarize the analyses of the computer runs. An "X" denotes a condition under which the system fails to meet minimum pressure requirements.

3. The system described by Alternative A2 (leak repair) improves the existing system in the Calhoun, Gualo Rai, Kagman, San Vicente, and Tasa villages for some peak and fire flow conditions (see Tables D1 and D2). The fact that some systems fail to meet minimum pressures in every flow condition

Table D1

Results of Water Distribution Model (Existing System - Alternative A1/D1)

Village	Normal Use		Peak Use		Fire Flow Residential		Fire Flow Hotel	
	2000	2040	2000	2040	2000	2040	2000	2040
Calhoun				X	X	X	NA	NA
Capitol Hill							NA	NA
Gualo Rai						X	NA	NA
Isley	X	X	X	X	X	X	X	X
Kagman		X	X	X	X	X	NA	NA
Kobler	X	X	X	X	X	X	NA	NA
Puerto Rico							X	X
San Vicente			X	X	X	X	NA	NA
Tasa	X	X	X	X	X	X	NA	X

X - Does not meet minimum pressure requirement.
NA - Not applicable.

Table D2

Results of Water Distribution Model (Existing System with Leak Repair - Alternative A2/D1)

Village	Normal Use		Peak Use		Fire Flow Residential		Fire Flow Hotel	
	2000	2040	2000	2040	2000	2040	2000	2040
Calhoun					X	X	NA	NA
Capitol Hill							NA	NA
Gualo Rai							NA	NA
Isley	X	X	X	X	X	X	X	X
Kagman				X	X	X	NA	NA
Kobler	X	X	X	X	X	X	NA	NA
Puerto Rico							X	X
San Vicente					X	X	NA	NA
Tasa			X	X	X	X	NA	X

X - Does not meet minimum pressure requirement.
NA - Not applicable.

Table D3

Results of Water Distribution Model (CE Maguire, Inc., Recommendations Without Leak Repair - Alternative B1)

Village	Normal Use		Peak Use		Fire Flow Residential		Fire Flow Hotel	
	2000	2040	2000	2040	2000	2040	2000	2040
Calhoun				X			NA	NA
Capitol Hill							NA	NA
Gualo Rai							NA	NA
Isley							X	X
Puerto Rico							X	X
San Vicente			X	X	X	X	NA	NA
Tasa			X	X	X	X	NA	X

X - Does not meet minimum pressure requirement.
NA - Not applicable.

Table D4

Results of Water Distribution Model (CE Maguire, Inc., Recommendations With Leak Repair - Alternative B2)

Village	Normal Use		Peak Use		Fire Flow Residential		Fire Flow Hotel	
	2000	2040	2000	2040	2000	2040	2000	2040
Calhoun							NA	NA
Capitol Hill							NA	NA
Gualo Rai							NA	NA
Isley							X	X
Puerto Rico							X	X
San Vicente			X	X	X	X	NA	NA
Tasa			X	X	X	X	NA	X

X - Does not meet minimum pressure requirement.
NA - Not applicable.

indicates that improvements beyond leak repair (e.g., main replacement, different operation) are necessary. The CE Maguire, Inc., recommendations (see Tables D3 and D4) do not provide a system with adequate pressures in San Vicente and Tasa for peak and fire flow conditions and in Isley and Puerto Rico for hotel fire flow conditions. The additional effort of service lateral repair (Alternative B2) does not significantly improve the Saipan distribution system over main replacement alone (Alternative B1), as shown by Table D4.

APPENDIX E: FUTURE USE OF DISTRIBUTION MODEL

1. The Saipan water distribution model of the existing system can become a powerful management tool if properly utilized by the Commonwealth of the Northern Mariana Islands or a contractor. For example, it can be used to:

   a. Test the effect of installing new pipes, tanks, valves, or pumps.

   b. Test the effect of shutting off several pumps or wells due to contamination.

   c. Test the effect of interconnecting systems.

   d. Predict pressures under different use rates.

   e. Select least cost combinations to meet needs.

2. The model users should construct separate data files representing the existing distribution system and various proposed systems for several time frames (e.g. years 2000 and 2040). The data for the existing distribution system should be kept up-to-date by adding data for any new pipes, pumps, pressure-reducing valves, check valves, etc. Use of the model with separate data files for each proposed system will give the user an accurate understanding of the impact of each modification. It is also very easy to run the program for various water use rates or simulated fire needs.

3. The model can be used for a more intensive study of the Saipan system once decisions have been made regarding which wells are to be added/abandoned and what distribution changes are to be made. Assistance in using this program can be obtained by contacting Tom Walski at the US Army Engineer Waterways Experiment Station at 601-634-2380.

APPENDIX F: SUMMARY OF NOMENCLATURE FOR ALTERNATIVES

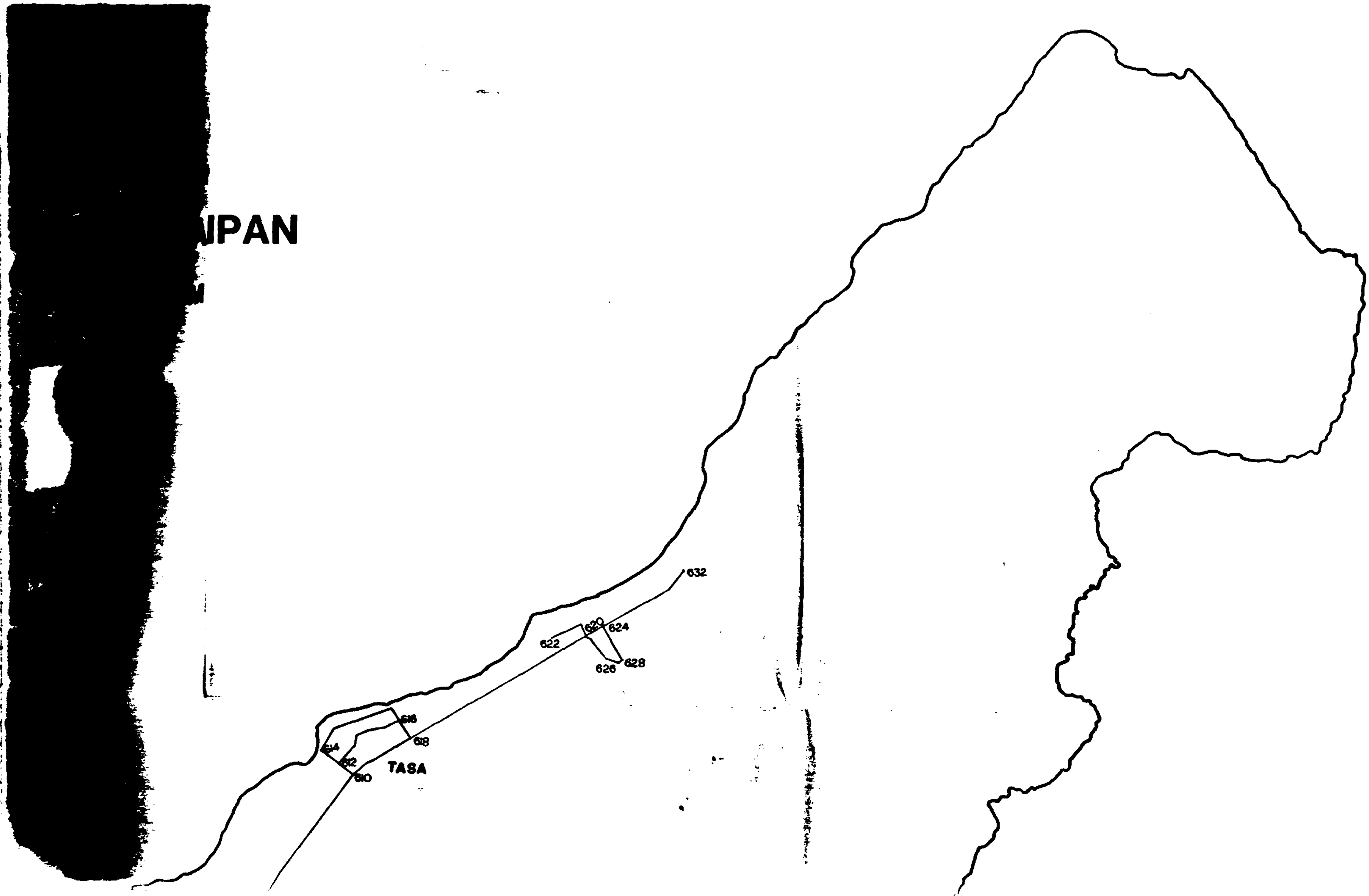
Type of Alternative	Alternative Number	Alternative Description
Source	A1	Existing sources, no leak repair
	A2	Existing sources, leak repair
	A3	Existing sources, adding new sources, no leak repair
	A4	Existing sources, adding new sources, leak repair
	A5	Abandon poor quality wells, add new sources, no leak repair
	A6	Abandon poor quality wells, add new sources, leak repair
Distribution (CE Maguire, Inc., recommendations)	B1	CE Maguire, Inc., recommendations, no repair of service laterals
	B2	CE Maguire, Inc., recommendations, replacement of service laterals
Distribution (US Army Engineer Waterways Experiment Station recommendations)	D1	Existing system and operations
	D2	Reduce number of separate systems and use of automatic valves
	D3	Complete replacement of system
	D4	Dual system

ISLAND OF SAIP

WATER SYSTEM

PIPE NUMBER	BEGINNING NODE	ENDING NODE	PIPE DIAMETER INCHES
[illegible]	[illegible]	[illegible]	6
[illegible]	[illegible]	[illegible]	6
[illegible]	[illegible]	[illegible]	6
[illegible]	6	10	6
[illegible]	8	20	8
10	10	12	8
[illegible]	12	14	6
[illegible]	16	18	6
[illegible]	18	20	8
20	20	22	8
24	20	24	8
28	24	28	8
30	28	30	8
32	30	32	8
34	32	36	8
36	36	40	8
37	36	37	6
40	40	42	6
41	40	41	8
42	42	46	6
45	42	43	6
46	46	50	6
47	46	47	6
50	50	54	6
51	50	51	6
55	54	55	6
63	63	67	6
67	67	79	6
72	72	73	6
76	72	78	6
78	78	96	8
79	73	79	6
80	72	80	6
82	80	82	6
84	80	84	6
89	72	89	6
90	72	90	12
94	72	94	18
95	41	96	8
96	96	98	8
100	94	100	6
102	94	106	6
103	100	103	6
107	106	107	6
109	109	129	6
112	106	112	6
115	112	115	6
116	112	116	6
119	116	119	6
120	116	120	6
121	120	121	6
126	94	126	18
128	126	128	18
129	129	130	4
131	129	131	4
134	134	136	4
136	136	138	6
138	28	138	8
148	148	149	8
149	138	149	8
150	148	150	8
152	148	152	8
154	152	154	8
155	154	158	8
156	154	156	6
158	156	158	6
160	158	160	8
162	160	162	8
164	160	164	6
166	152	166	6
168	166	168	6
170	130	171	8
171	170	171	8
172	170	172	8
174	172	174	8
175	174	175	8
176	176	178	8
177	129	177	6
178	178	180	8
180	174	180	8

PIPE NUMBER	BEGINNING NODE	ENDING NODE	PIPE DIAMETER INCHES
318	316	318	8
315	288	316	12
320	304	320	4
350	320	350	8
352	350	352	8
354	354	368	8
355	354	356	8
356	315	356	12
358	356	358	6
359	359	364	6
360	358	360	6
361	360	362	6
362	358	362	6
363	359	363	6
364	359	362	6
367	364	367	6
370	368	370	8
372	368	372	8
373	372	374	8
374	374	376	6
376	376	378	6
377	376	377	6
378	378	380	6
380	380	412	12
381	378	382	6
382	372	382	6
383	380	384	12
384	382	384	6
385	384	386	12
386	356	386	12
388	388	390	8
390	390	392	6
392	392	408	6
394	392	394	6
395	394	396	6
396	396	397	6
397	397	400	8
398	390	398	8
399	396	398	6
401	400	402	8
402	398	402	8
404	402	404	8
406	404	406	8
407	397	408	8
409	408	410	8
410	388	410	8
411	410	456	6
412	412	414	6
413	374	414	8
414	414	416	8
416	416	418	6
418	418	438	6
419	418	420	6
420	420	422	8
421	420	436	8
422	416	422	8
424	422	424	8
426	424	426	8
427	426	430	8
428	426	428	8
430	430	431	8
431	431	432	8
432	432	434	6
433	431	433	6
434	434	460	6
436	434	436	6
438	436	438	8
440	438	440	8
442	432	442	8
443	442	444	8
444	430	444	8
445	444	446	8
446	446	450	8
448	446	448	8
450	442	450	6
452	450	452	6
454	424	454	8
456	456	458	8
460	454	460	12
461	461	[illegible]	[illegible]



IPAN
TASA
632
620
624
622
626
628
616
618
614
612
610

47	46	47	6
50	50	54	6
51	50	51	6
55	54	55	6
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460	454	460	12
461	461	462	6
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476	474	476	8
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481	480	488	6
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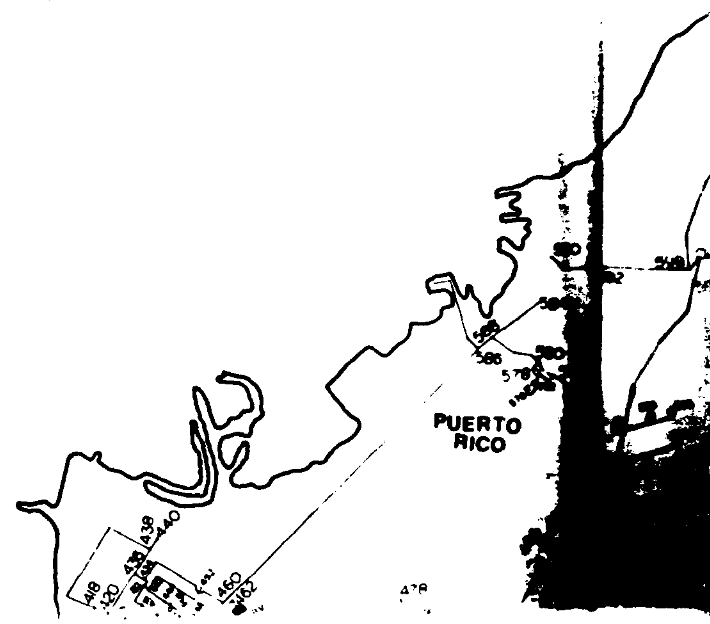

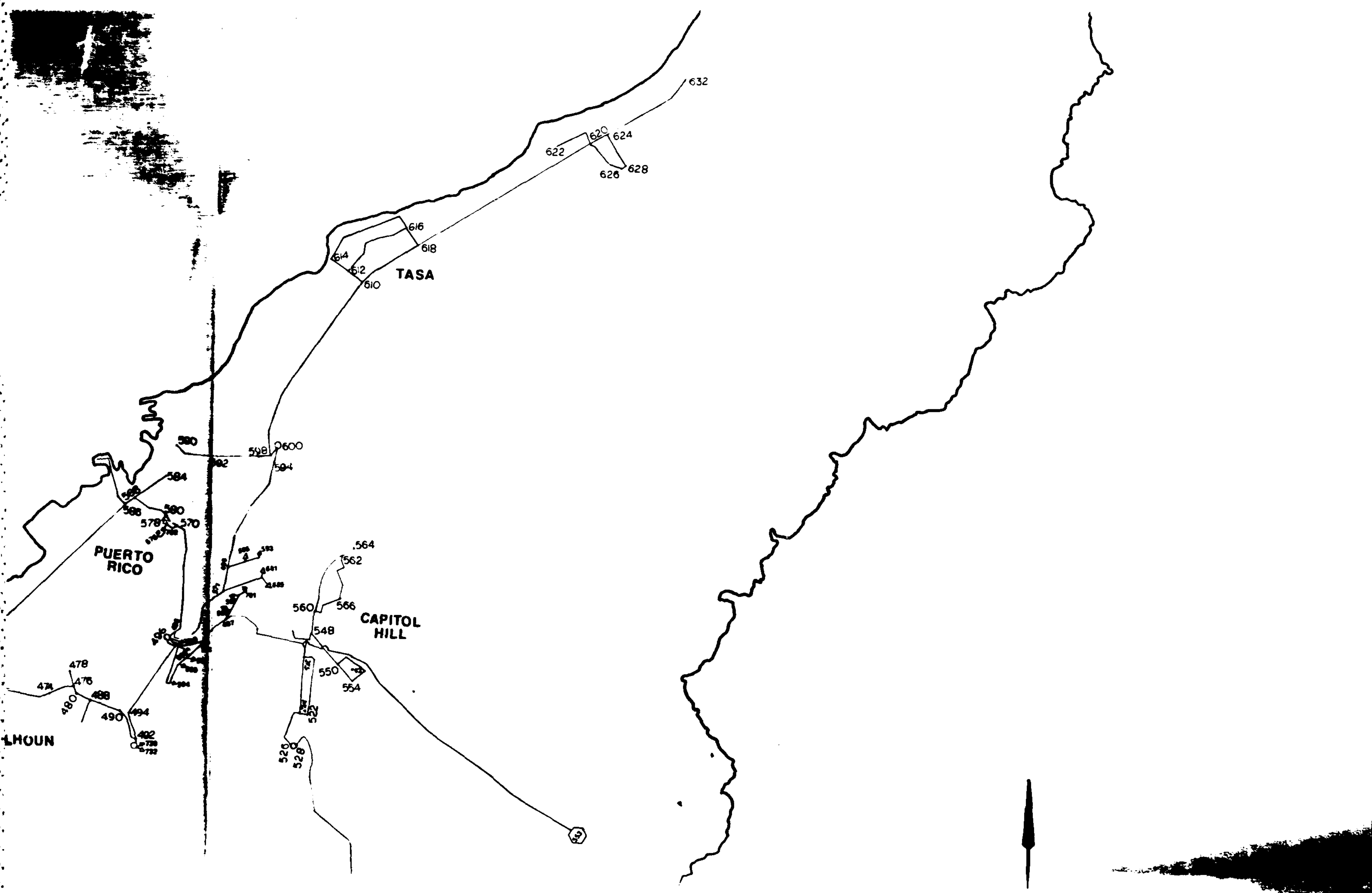

TASA
CAPITOL
HILL
PUERTO
RICO
LHOUN
632
620
624
622
626
628
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618
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612
610
600
598
594
580
584
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566
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490
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492

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262	246	262	12
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272	272	276	8
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314	296	314	8
315	294	315	8
316	315	316	12
147	147	150	8
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570	570	578	12
571	498	571	8
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577	572	577	6
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581	580	588	12
584	584	588	12
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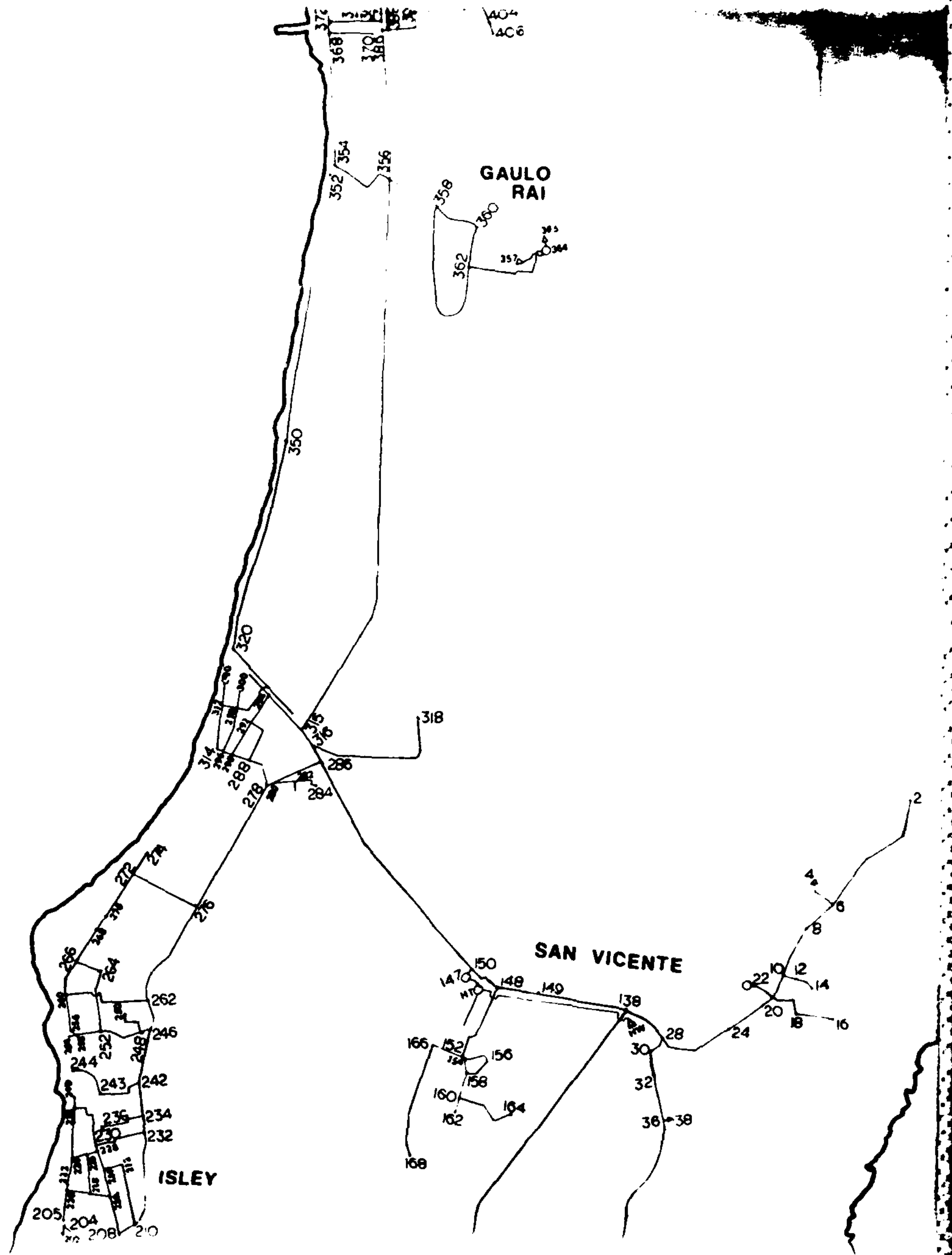
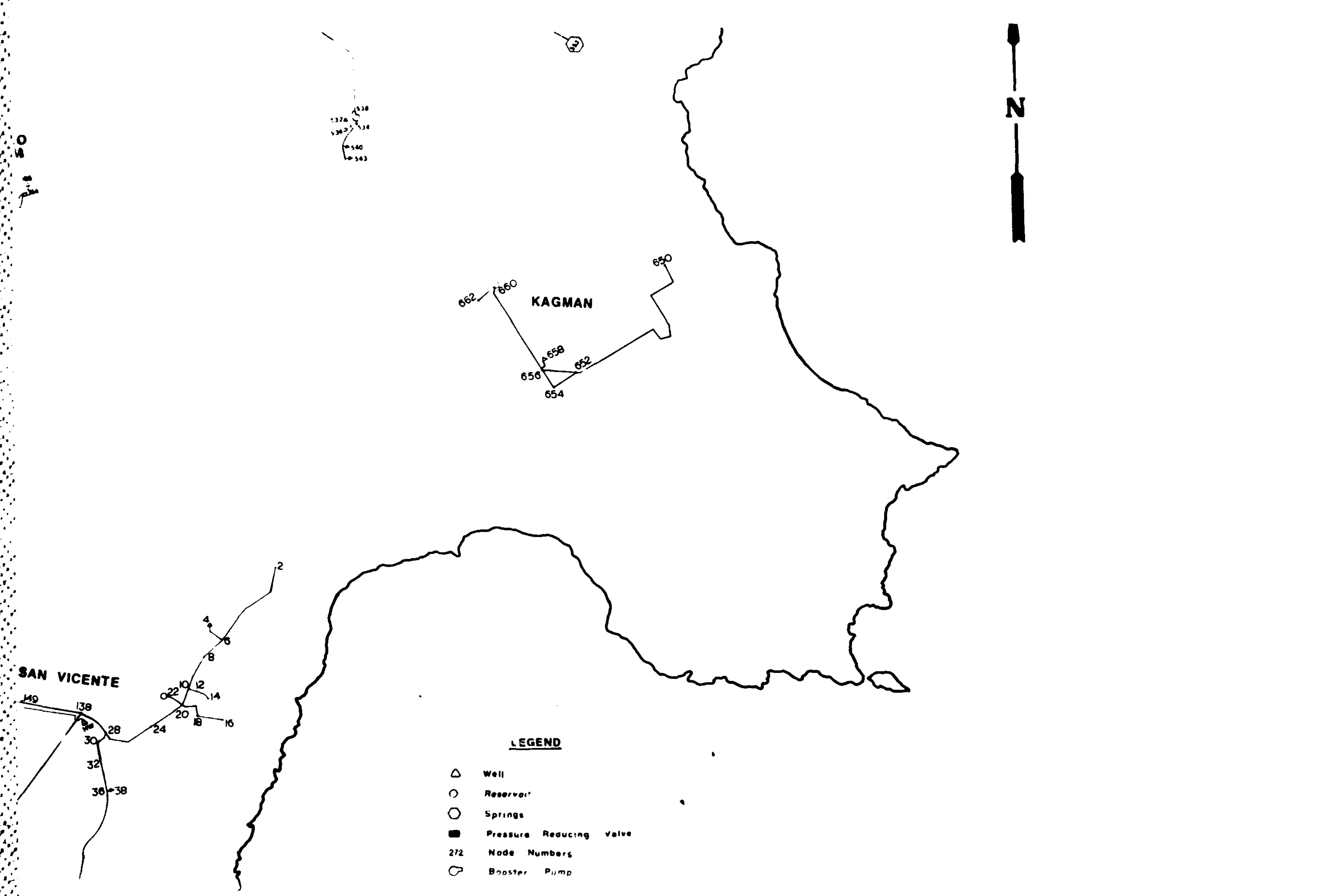
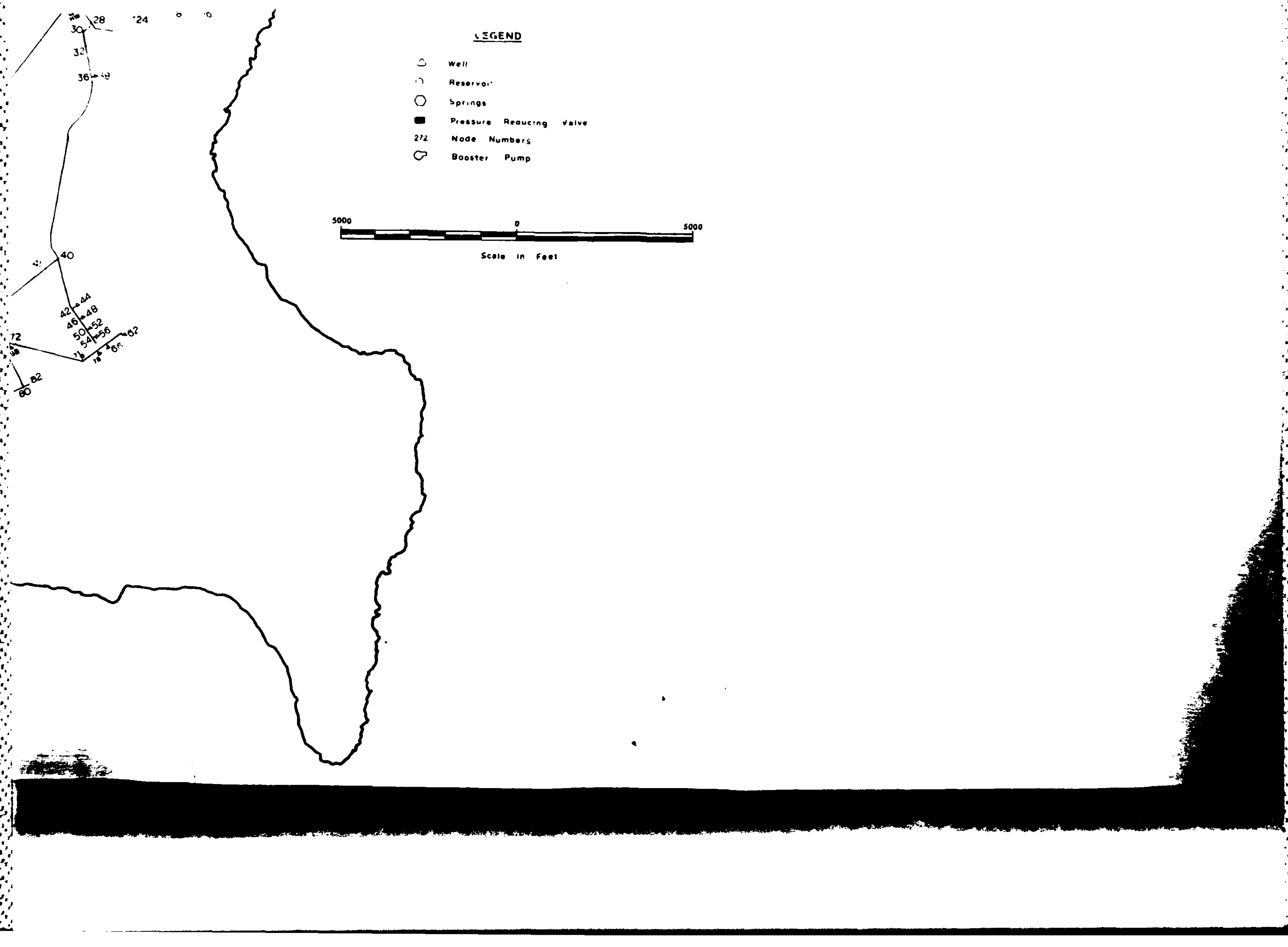
656	656	660	4
658	652	656	4
660	660	662	4
691	496	691	6
699	496	699	6
703	534	703	6
731	492	731	6
733	492	733	6
735	412	454	12
591	591	597	6
594	594	600	6
597	499	597	6
683	571	683	6

VILLAGE	PUMP NUMBER	SUCTION NODE	DISCHARGE NODE	W-Well Pump B-Booster Pump
SAN VICENTE	4	4	5	W
	38	38	37	W
	44	44	43	W
	48	48	47	W
	52	52	51	W
	56	56	55	W
ISLEY	62	62	63	W
	66	66	67	W
	69	69	75	W
	71	71	73	W
	88	88	89	W
	91	91	90	W
	101	101	103	W
	108	108	107	W
	114	114	115	W
	118	113	119	W
	122	122	121	W
KOBLER	110	110	109	W
	132	132	131	W
	173	173	177	W
GUALO RAI	357	357	367	W
	365	365	363	W
CAPITOL HILL	532	532	531	W
	535	534	538	B
	536	536	703	W
	537	534	538	B
	540	540	539	W
	543	543	541	W
	556	553	555	B
TASA	593	593	591	W
	595	595	597	W
	504	504	505	W
	508	508	509	W
	512	512	513	W
	514	514	515	W
	[illegible]	[illegible]	[illegible]	[illegible]




N
KAGMAN
650
652
654
656
658
660
662
SAN VICENTE
2
4
6
8
10
12
14
16
18
20
22
24
28
30
32
36
38
138
149
LEGEND
Well
Reservoir
Springs
Pressure Reducing Valve
272 Node Numbers
Booster Pump


LEGEND
Well
Reservoir
Springs
Pressure Reducing Valve
272 Node Numbers
Booster Pump
5000
0
5000
Scale in Feet
28
24
30
32
36
40
42
44
46
48
50
52
54
56
62
66
72
80
82

	[illegible]	132	131	W
	173	173	177	W
GUALO RAI	357	357	367	W
	365	365	363	W
CAPITOL HILL	532	532	531	W
	535	534	538	B
	536	536	703	W
	537	534	538	B
	540	540	539	W
	543	543	541	W
	556	553	555	B
TASA	593	593	59[illegible]	W
	595	595	597	W
PUERTO RICO	504	504	505	W
	508	508	509	W
	512	512	513	W
	514	514	515	W
	561	561	563	W
	565	585	567	W
	576	576	577	W
	681	681	683	W
	685	685	683	W
	690	690	691	W
	698	698	699	W
	701	701	575	W
	702	702	572	W
KAGMAN	657	658	655	W
CALHOUN	730	730	731	W
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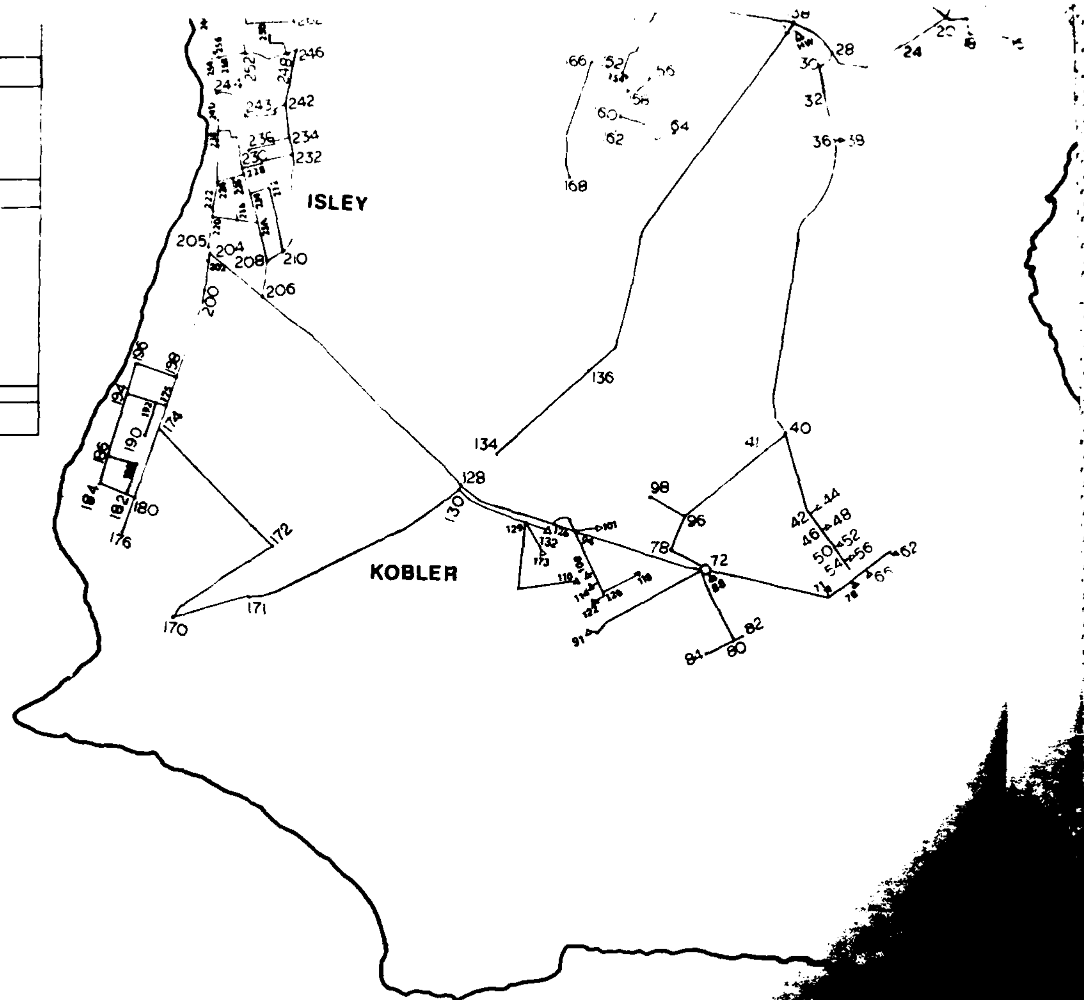

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